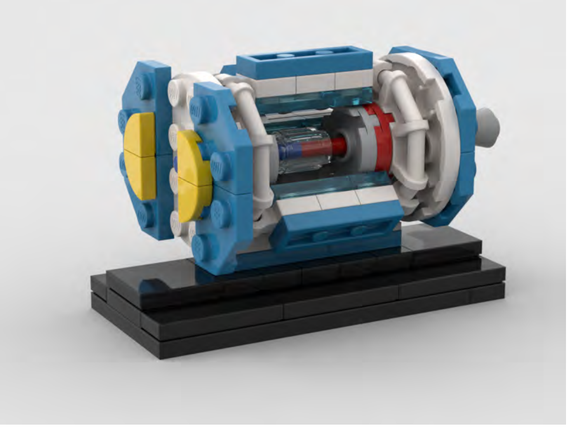


Stato di Belle2 e prospettive 2024

Riunione CSN1
12/09/2023
A. Passeri

Outline:

- Attività in corso durante lo shutdown (LS1)
- Intensa attività di analisi
- Piani per l'upgrade
- Run Plan 2024-26

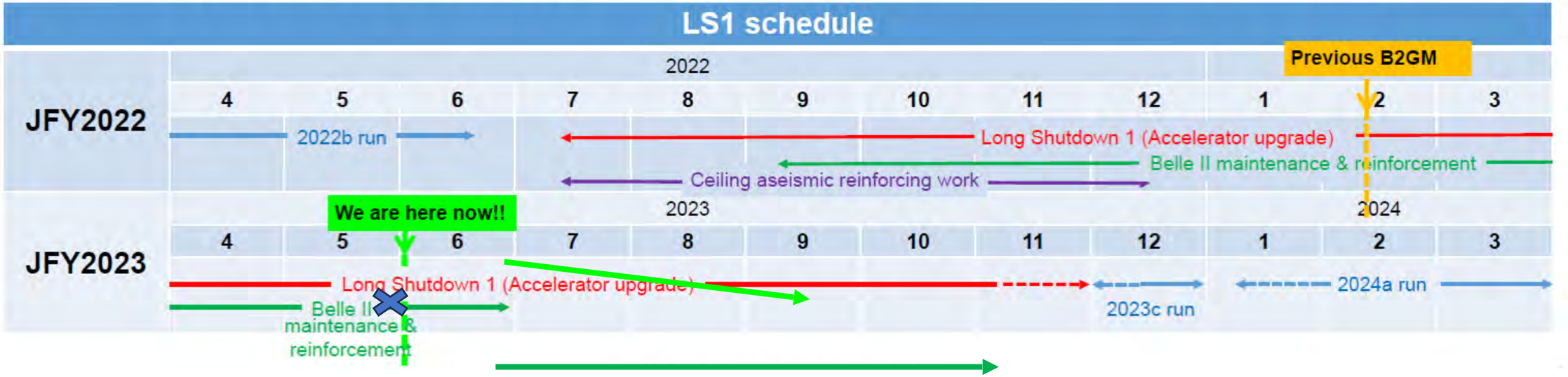
LS1 schedule

Con l'installazione di PXD2, la ripartenza di SuperKEKB è fissata a dicembre 2023

- **LS1 : ~15 months from July 2022 to autumn 2023**
  - **2022b run stopped earlier than planned due to high electricity costs (22nd June), but LS1 major works began on 11th July as scheduled.**
  - **Beam operation will restart from December 2023.**
- **Major works during LS1 other than accelerator upgrade:**
  - **Belle II maintenance and reinforcement**
    - Replacement of PXD and TOP MCP-PMTs, new IP beam pipes, and so on.
    - IR works are required, including QCS extraction & reinstallation, disassembly & reinstallation of magnets, beam pipes, radiation shields, etc.
  - **Aseismic reinforcement of the ceiling at the laboratory buildings (Oho Lab. & Fuji Lab.)**
    - It took about 5 months and it could be done only during long shutdown.
    - During this work, we could not use ceiling crane required for NLC construction at Oho Lab.!!

Ceiling aseismic reinforcing work

S. Nakamura



SuperKEKB issues

Limitations found so far

- While we have been confronting various difficulties during operation, the underlying issues became evident in 2020c. Identified challenges are as follows:
  - Shorter beam lifetime than expected
    - As a result, the maximum bunch currents are limited by the balance between the lifetime and the injection power.
  - Lower bunch-current limit than expected due to TMCI
    - Due to higher impedance of beam collimators, in which the apertures are smaller than the design values to suppress high background.
  - Beam-beam effect (vertical beam size blow-up)
    - Relaxed by the crab-waist collision scheme, but still remains.
  - Low operation efficiency
    - Operation efficiency during 2021a, b is almost 0.5, lower than expected one, 0.65.
    - Machine tunings, machine troubles, maintenance, etc.
  - Aging of hardware and facilities, and so on.
- Various measures to solve these challenges have been also discussed at the same time.

Prosegue l’implementazione delle contromisure alle limitazioni di luminosità osservate:

	Aim	Possible countermeasures	
(1)	· Increase injection power (efficiency)	Linac upgrade to designed specification	
		Large physical aperture at electron injection point (HER)	During LS1
		Linac upgrade beyond designed specification	
(2)	· Relax beam-beam effect · Expand dynamic aperture	Utilizing rotatable sextuplole magnets (LER)	Done before LS1
		“Perfect matching”	Under consideration (It was found that it is not easy.)
		QCS modification (Option#1): Move QC1RP to the far side of IP	Under consideration
		Larger scale QCS modification (Option #8)	
(3)	· Suppress BG · Expand physical aperture	QCS cryostat front panel modification and additional shield to IP bellows	During LS1
		Optimization of collimator location	Done before LS1
		Enlargemen of QCSR beam pipe (Option#3)	Under consideration
(4)	· Relax TMCI limit	“Non-linear collimator”	During LS1
(5)	· Improve stability	Robust collimators	During LS1 (Partially)
		Upgrade of beam abort system and loss monitor system	During LS1 (Partially)
(6)	· Anti-aging measures	Preparation of standby machines and spares, repair of facilities, etc.	During LS1 (Partially)

In corso numerosi interventi sul rivelatore Belle2 :

Coinvolgimento italiano

PI, TS	PXD/SVD	PXD commissioning plan in KEK (done) VXD reinstallation
	CDC	HV resister replacement Improvement in gas circulation and monitoring
PD, TO	TOP	TOP MCP-PMT replacement (done)
PG, NA	ECL	Improvement in pedestal correction Gain adjustment on ShaperDSP (done)
RM3, LNF	KLM	Reinforcement of monitoring system NH3 injection for BB2 efficiency recovery
	TRG	Improvements in CDCTRG, ECLTRG, KLMTRG Optimization of trigger veto, and TOPTRG
	DAQ	PCIe40 long-term stability test with realistic high-occupancy data
TS	Background	Additional neutron shields
TS	MDI	Installation of additional loss monitors Non-linear collimator

+ additional shield around QCS bellows

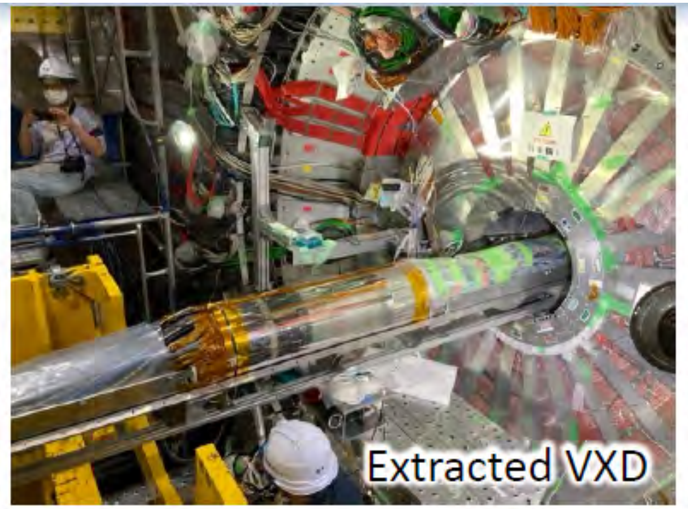
+ modified diamond abort during injection

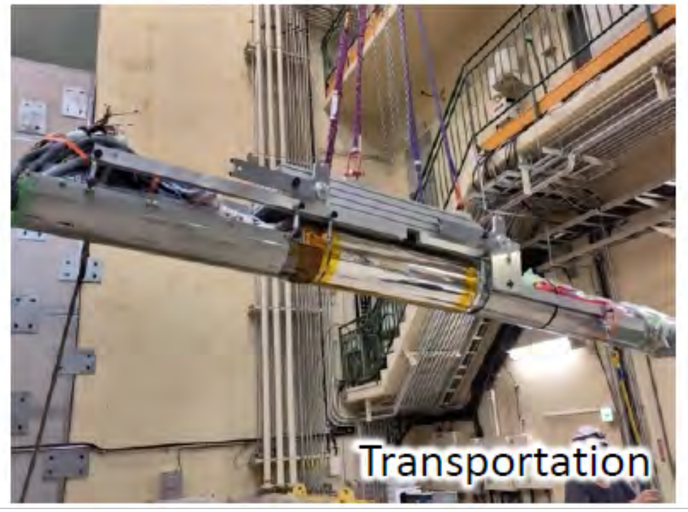
PXD2 trasportato al KEK a marzo

Installato sulla nuova IR, superati i test di cooling

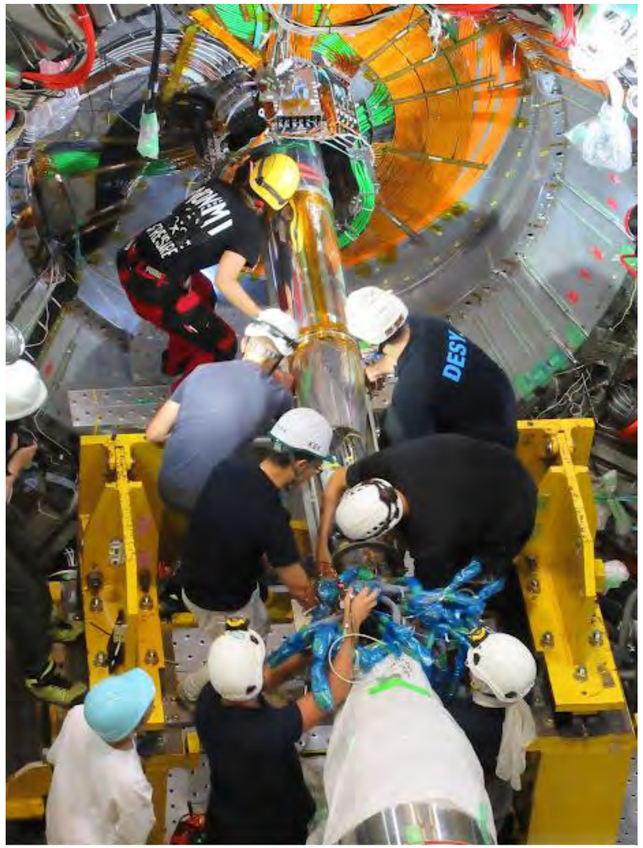
- **Improve ladder gliding functionality:**
  - Introduce additional foil underneath FWD washer
  - Ladder glue-joint reinforcement on HS_2p4
  - Reduce the FWD screw torque to 7.5 mNm
- **PXD2 mounting on new BP was completed on Apr 5.**
- **Full PXD2 cooling test: Apr 17-20**
  - While the gliding property of PXD2 has been largely improved, in the full PXD2 operation a large deformation (500um-750um) was observed on two ladders and medium deformation on one ladder.
  - The deformation is mitigated if we power off these specific modules.
- **TB/EB-joint meeting on Apr 21:** https://indico.belle2.org/event/9196/
  - The community granted the green-light of the VXD reinstallation as scheduled.
    - Stress test on the glue joint of L2 dummy ladder in DESY (preventing gliding to deliberately causing pre-defined sagittas more than 100k cycles) confirmed the ladder can mechanically survive after many cycles of 1.2mm or more deformation.
    - one PX1 L2 ladder survived for 4 years in Run1 with ~500um sagitta.
    - At any time there is an option to power off these modules if we decide the deformation is too large. The deformation can be mesasured in-situ using cosmic and beam.

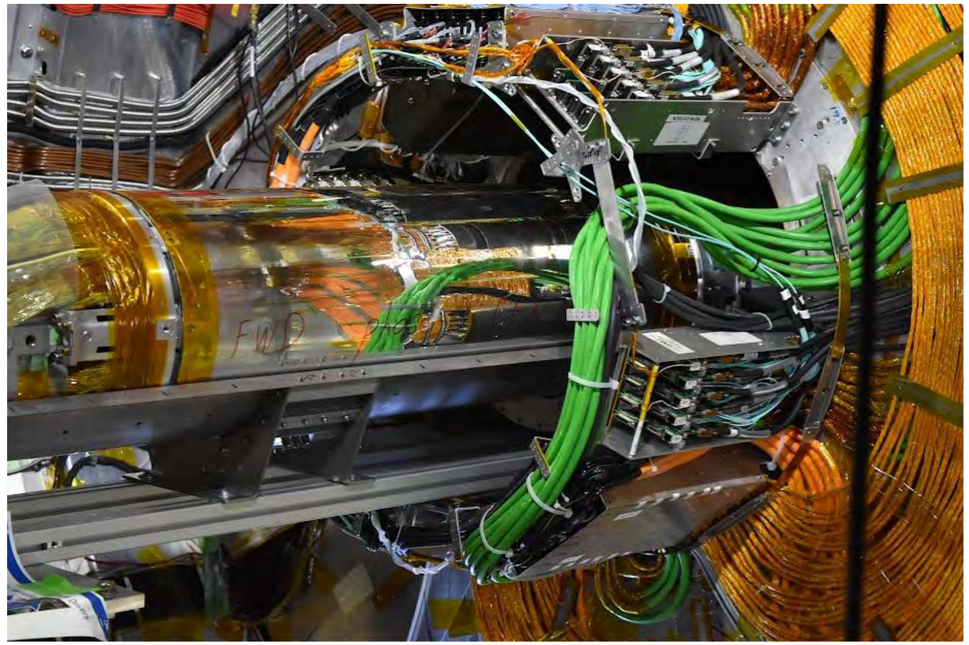
Estrazione VXD 10 maggio:





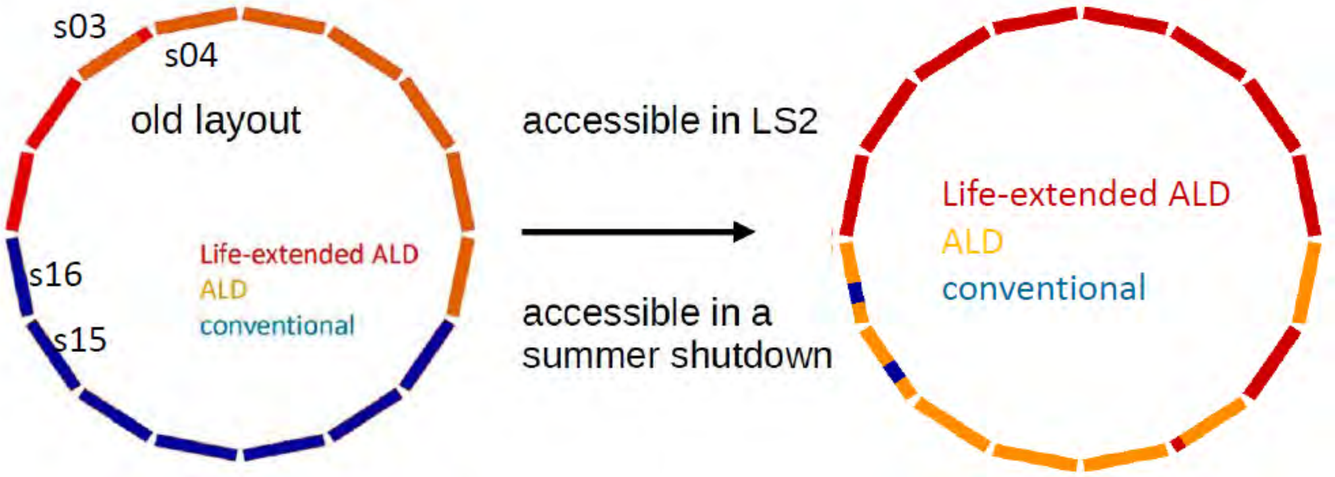
VXD re-inserito nel detector il 28 luglio



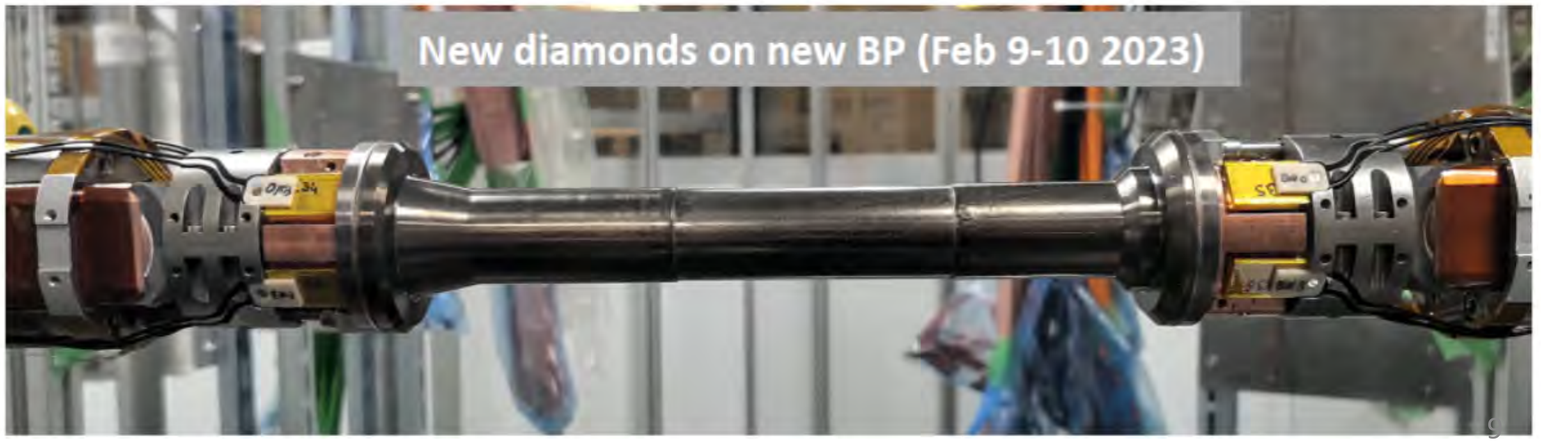


- Cabling and piping completed in august
- ECL insertion test done last week
- PXD grounding switches installed and tested
- Dry volume closed and sealed
- Start VXD commissioning mid september

Sostituzione MCP-PMT del TOP completata
Laser test delle performance superato.

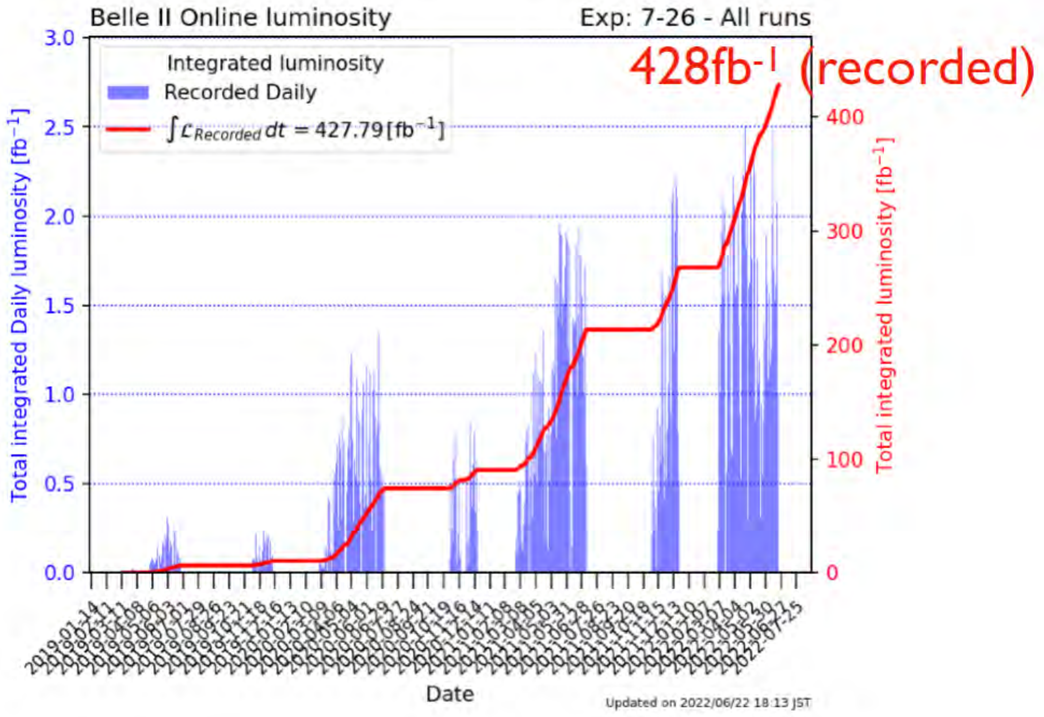


8 sensori di radiazione al diamante installati già a febbraio sulla nuova beam pipe.



Intensa attività di analisi sul campione raccolto finora:

Record luminosità istantanea: 4.17×10^{34} cm^{-2}s^{-1}



2 highlights:

- $B^+ \rightarrow K^+ \nu \nu$
- R(X)

EPS 23

Measurement of the Ds lifetime — world leading, arXiv: 2306.00365
Y(nS) dipion transitions— unique, paper in preparation
Search for $ee \rightarrow \omega\eta b$ at 10.75 GeV — unique, paper in preparation
CPV in B0 -> eta' Ks— unique, paper in preparation
CPV in B0 -> Ks pi0 gamma— unique and world leading paper in preparation
GNN and sin2phi1— paper in preparation
R(D*) — high profile — paper in preparation
R(X) — high profile, unique — paper in preparation
Evidence for B+ -> K+ nunu — high profile, unqiue — paper in preparation
BF and asymmetries in B -> rho gamma — unique, Belle +Belle II — paper in preparation
Search for Z' -> mumu — paper in preparation

Moriond 23

Energy-dependence of $B^{(*)}B^{(*)}$bar cross section — unique — paper in preparation
Test of light-lepton universality in $B \rightarrow D^* \ell \nu$ decays — unique — arXiv: 2308.02023
Measurement of CKM angle γ using GLW — Belle + Belle II, arXiv: 2308.05048
Measurement of CKM angle γ using GLS — Belle + Belle I, arXiv: 2306.02940
Search for long-lived spin-0 mediator in b → s transitions— world leading, arXiv: 2306.02830
Measurement of of the τ mass — world leading, PRD 108, 032006 (2023)
BF and ACP in $B^0 \rightarrow h^+ h^{0-}$ decays and isospin sum rule — world leading — paper in preparation
ACP in $B^0 \rightarrow K^0_S K^0_S K^0_S$ — paper in preparation
|Vcb| using untagged $B \rightarrow D^* \ell \nu$ decays — competitive — paper in preparation
CPV in $B^0 \rightarrow K^0\pi^0$ decays — competitive, arXiv: 2305.07555. Accepted
CPV in $B^0 \rightarrow \phi K^0_S$ – arXiv: 2307.02802,
Novel method for charm flavor tagging — unique, PRD 107, 112010 (2023)
Search for tau -> ell phi — arXiv: 2305.04759 (conf note)
Observation of B -> D(*)KKs — — world leading arXiv: 2305.01321 (conf note)

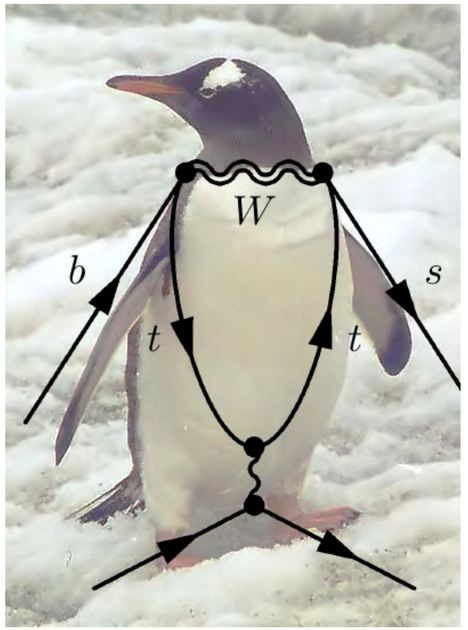
Measurement of $B^+ \to K^+ \nu\nu$ (I)

[E. Ganiev, S. Glazov @ EPS23]

- Reliable theoretical predictions

  $\mathcal{B}(B \to K \nu\bar{\nu}) = (5.58 \pm 0.38) \times 10^{-6}$ [arxiv:2207.13371]

  Branching fraction gets increased by leptoquarks, axions, etc.
- $B^+ \to K^+ \nu\bar{\nu}$ has never been experimentally observed



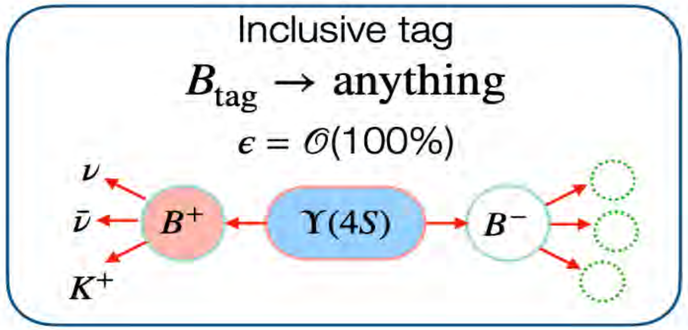
Search for $B^+ \to K^+ \nu\bar{\nu}$ is unique to Belle II

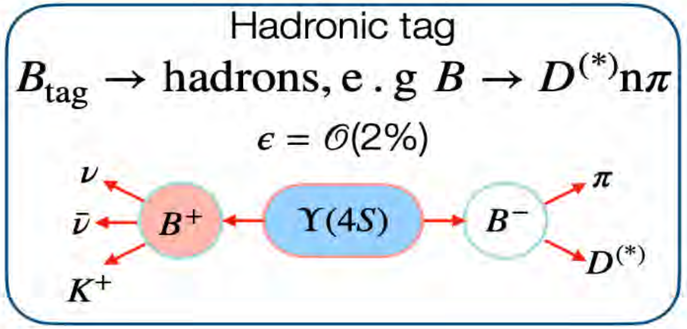
Challenge: two neutrinos in the final state

=> Information from partner B (tag) provides insight about signal B

=> Use inclusive-tag approach : analysis with innovative method and highest sensitivity

=> Use conventional hadronic-tag approach as an auxiliary measurement



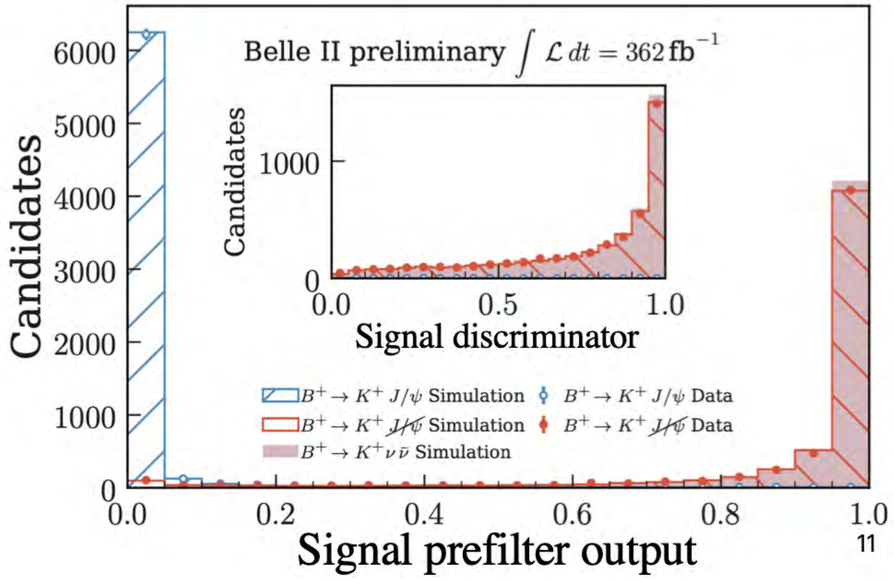


Full pre-LS1 dataset (362 fb^{-1}) used

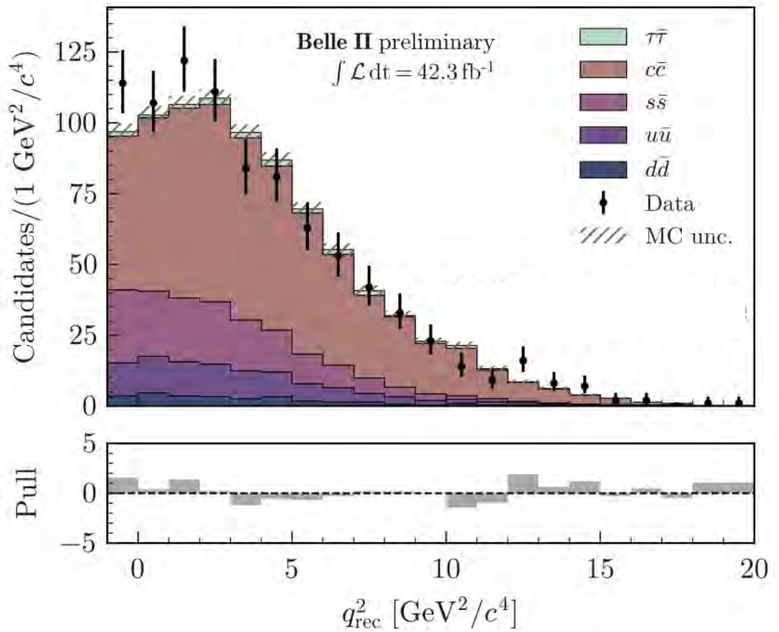
Measurement of $B^+ \to K^+ \nu\nu$ (II)

[E. Ganiev, S. Glazov @ EPS23]

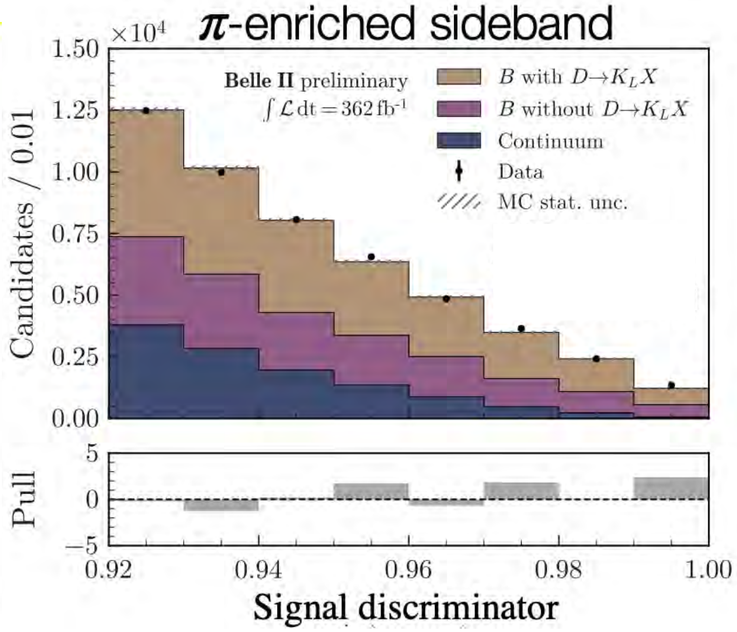
- Combine signal kaon, event topology, rest-of-event information in MVA classifiers
- Backgrounds:
  - $e^+e^- \to q\bar{q}$
  - other B decays
    - semileptonic B decays
    - potentially dangerous $B^+ \to K^+ n\bar{n}$, $B^+ \to K^+ K^0 \bar{K}^0$, pion fakes, $B \to X_c(\to K L + X)$
- Signal efficiency and background estimation corrected and validated using a variety of control channels:



Signal efficiency validated using $B^+ \to J/\psi K^+$ with J/ψ removed to match signal topology



off-resonance data used to study $e^+e^- \to q\bar{q}$ backgrounds



pion-enriched sideband used to study $B \to X_c(\to K_L + X)$ component

Measurement of $B^+ \to K^+ \nu\nu$ (III)

[E. Ganiev, S. Glazov @ EPS23]

Closure test on inclusive method:

Measure known decay mode to validate the method

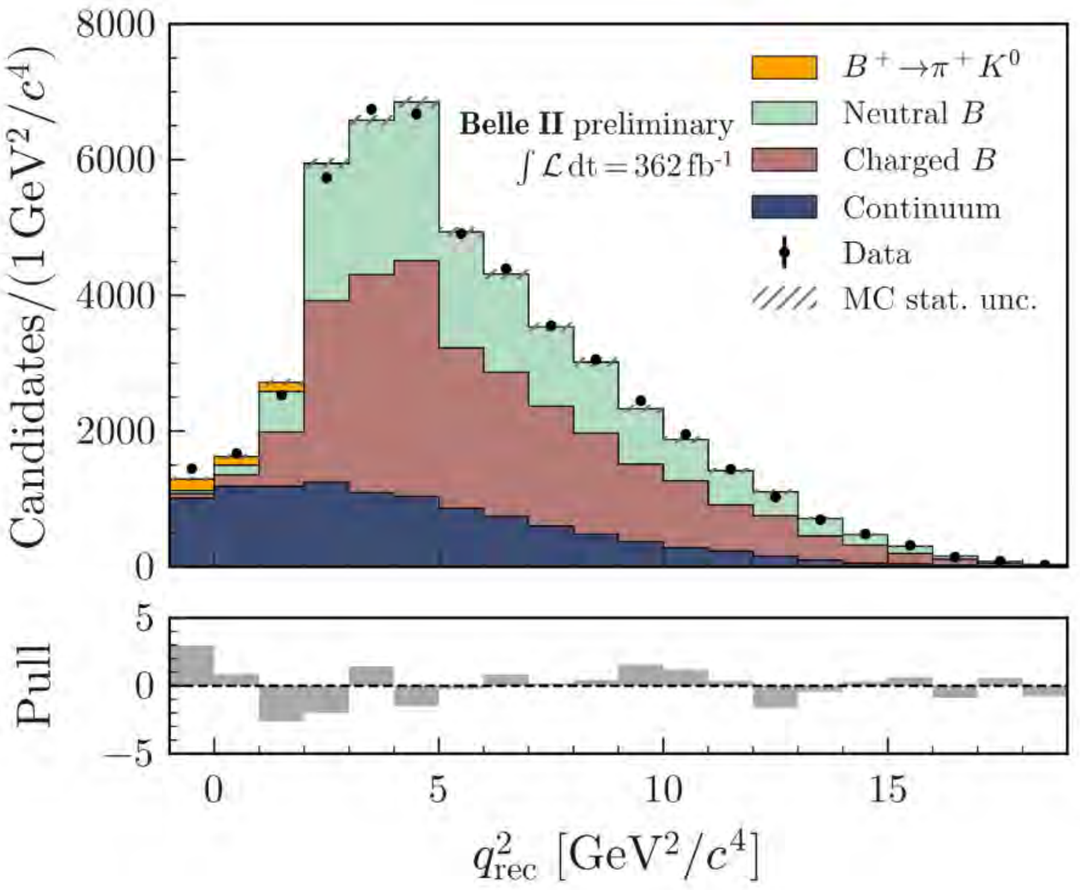
Minimally adapt $B^+ \to K^+ \nu\bar{\nu}$ to measure BF($B^+ \to \pi^+ K^0$)

$B^+ \to \pi^+ K^0$ has similar branching fraction to SM $B^+ \to K^+ \nu\bar{\nu}$

BF($B^+ \to \pi^+ K^0$) = (2.5 ± 0.5) x 10^{-5}

consistent with PDG [(2.38 ± 0.08) x 10^{-5}]

Test passed ✓



Measurement of $B^+ \to K^+ \nu\nu$ (IV)

[E. Ganiev, S. Galzov @ EPS23]

- Perform binned maximum likelihood fit
  - Inclusive tag: in bins of q^2 and classifier output
  - Hadronic tag: in bins of classifier output

  to measure μ = signal branching fraction in units of SM rate

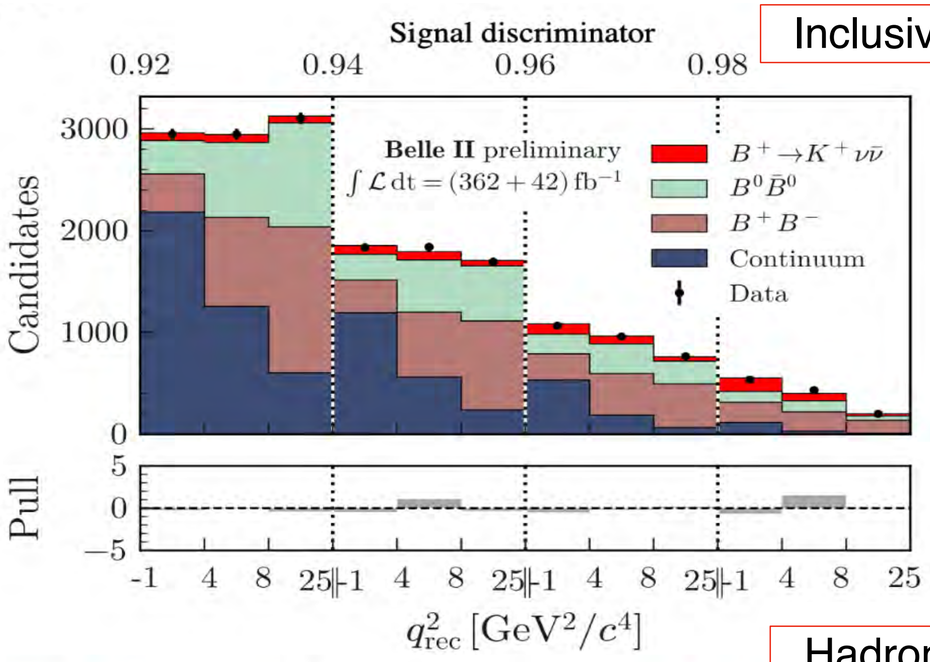
- Results:

- Inclusive tag: $\mu = 5.6 \pm 1.1(\text{stat})^{+1.0}_{-0.9}(\text{syst})$
- Hadronic tag: $\mu = 2.2 \pm 2.3(\text{stat})^{+1.6}_{-0.7}(\text{syst})$
- Combined: $\mu = 4.7 \pm 1.0(\text{stat}) \pm 0.9(\text{syst})$

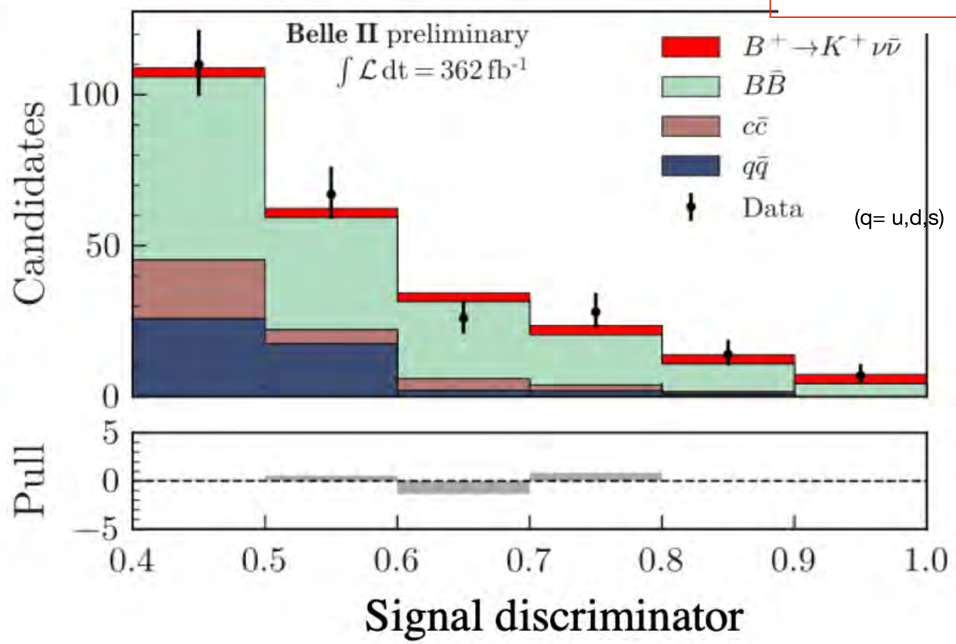
Results are consistent within 1.2σ

First evidence of the $B^+ \to K^+ \nu\bar{\nu}$ decay

Inclusive



Hadronic



Measurement of $B^+ \to K^+ \nu\nu$ (V)

[E. Ganiev, S. Galzov @ EPS23]

Inclusive tag: $\mathrm{BF} = [2.8 \pm 0.5 \pm 0.5] \times 10^{-5}$

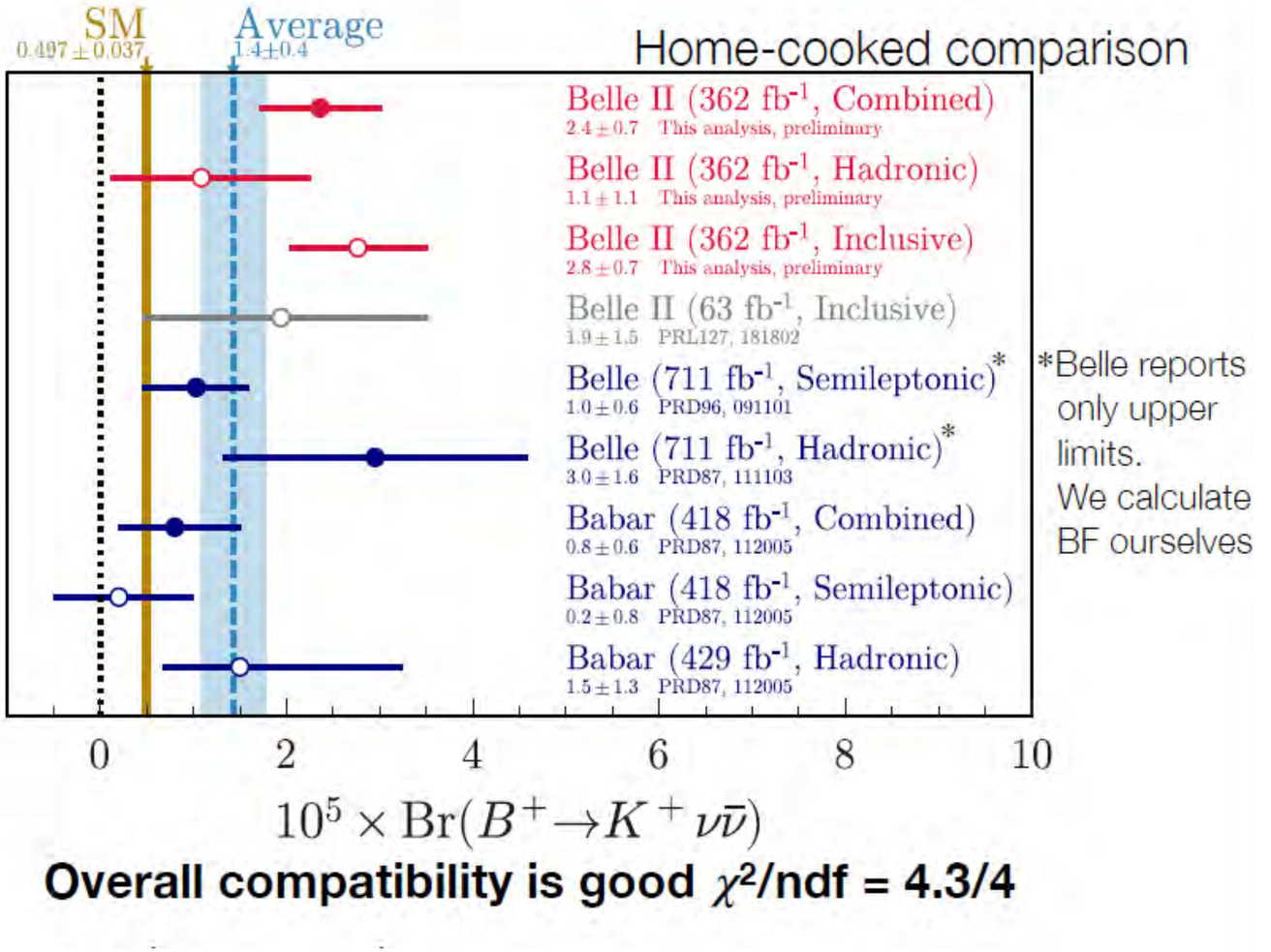
Hadronic tag: $\mathrm{BF} = [1.1^{+0.9+0.8}_{-0.8-0.5}] \times 10^{-5}$

Combined: $\mathrm{BF} = [2.4 \pm 0.5^{+0.5}_{-0.4}] \times 10^{-5}$

For the **inclusive tag**, significance of the result
- wrt null hypothesis is 3.6σ
- wrt SM is 3.0σ

For the **hadronic tag**, significance of the result
- wrt null hypothesis is 1.1σ
- wrt SM is 0.6σ

For the **combination**, significance of the result
- wrt null hypothesis is 3.6σ
- wrt SM is 2.8σ



R(X) measurement (I)

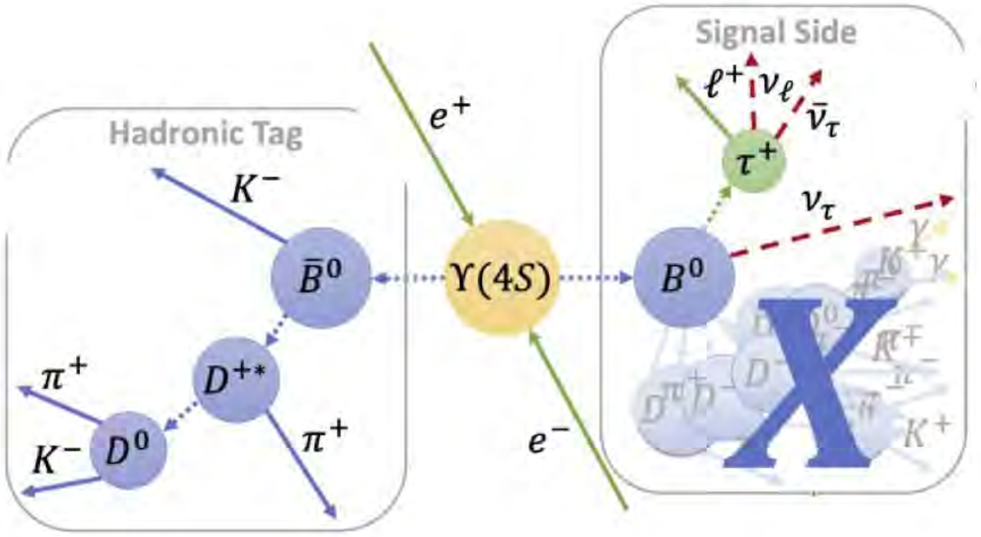
[T. Koga, S. Glazov @ EPS23]

-The first measurement of $R(X) = \frac{\mathcal{B}(B \to X\tau\nu_\tau)}{\mathcal{B}(B \to X\ell\nu_\ell)}$ at B factory, 189fb^{-1}

- -inclusive: complementary to exclusive analyses of R(D*)
- -one of unique and high-profile goals of BelleII

-Reconstruct $B \to X\tau\nu_\tau$, $B \to X\ell\nu_\ell$

- -B_{tag}: Hadronic tag
- -B_{sig}: Leptonic τ decays of $\tau \to e\bar{\nu}_e\nu_\tau / \mu\bar{\nu}_\mu\nu_\tau$
  e(μ) momentum^{lab} > 0.5(0.7) GeV
  Any other particles in final state (X)

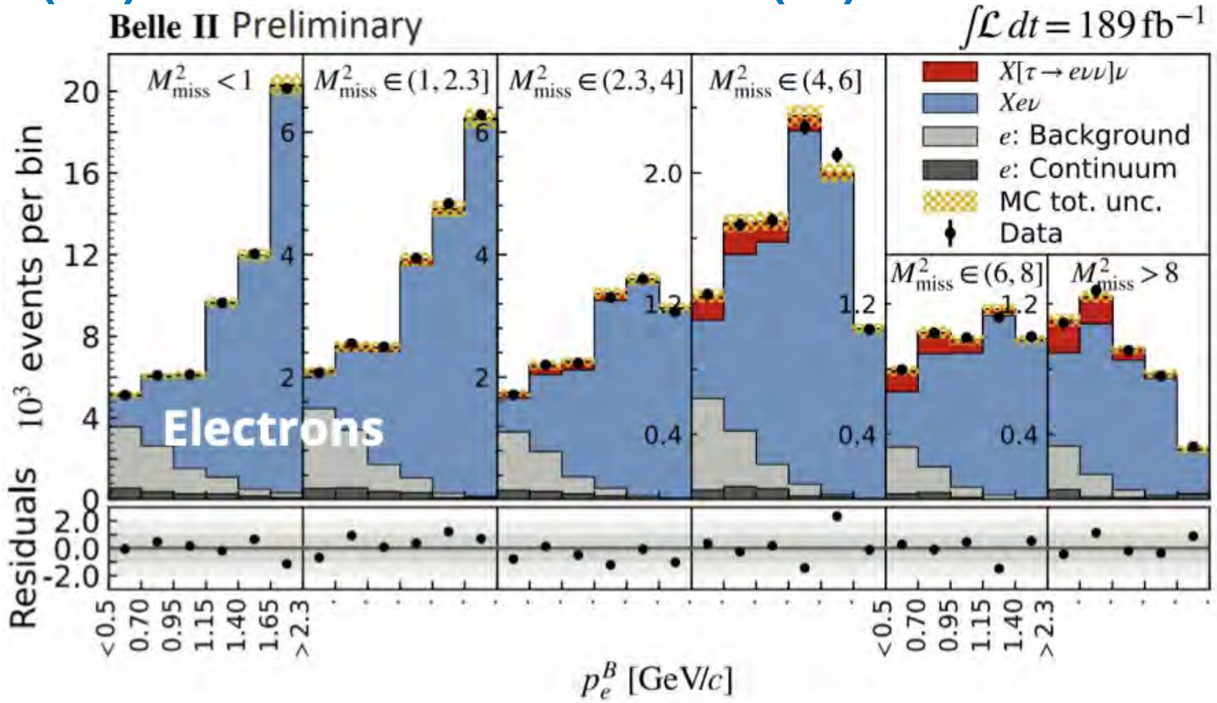


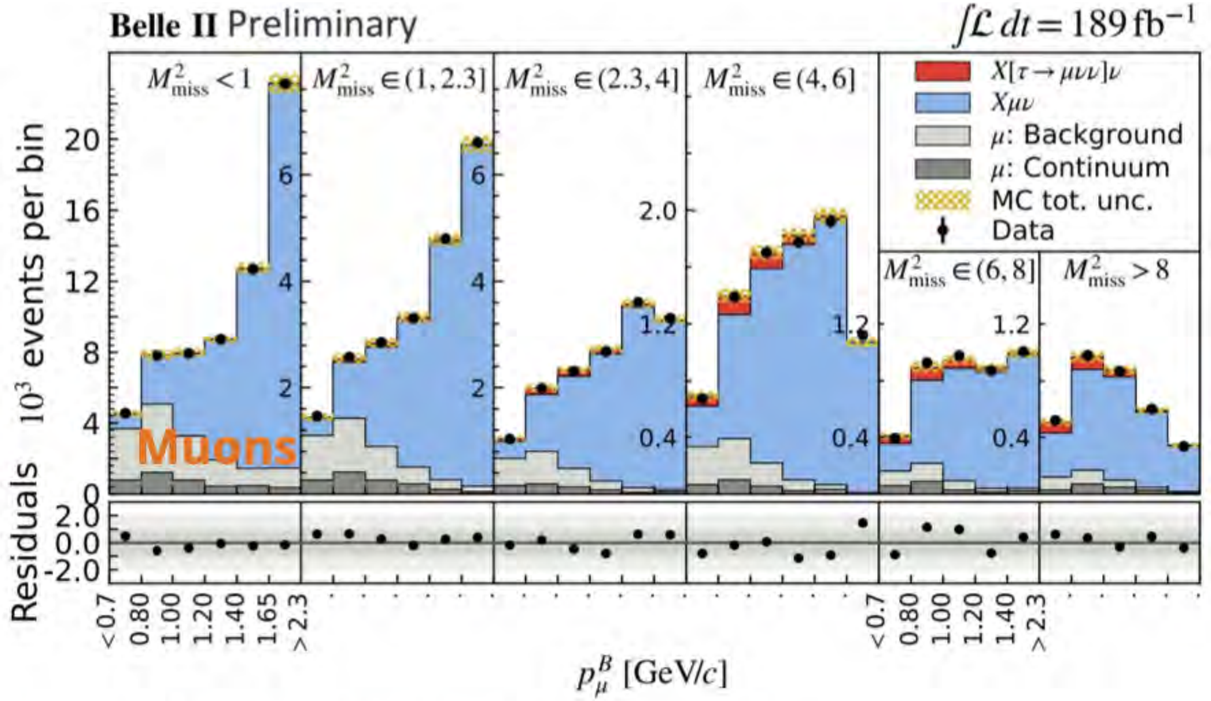
-Challenge: contamination and modeling of many decay channels

- -correct understanding of PDF shapes and background yields:
  PDF shapes are calibrated in side-band by using X mass distribution

R(X) measurement (II)

[T. Koga, S. Glazov @ EPS23]





Signal extraction: 2-dim binned likelihood for lepton momentum in B frame and squared missing mass

Complex analysis, requiring multiple corrections/reweighting to simulated samples
Excellent agreement between electron and muon channel measurements:

$$R(X_{\tau/e}) = 0.232 \pm 0.020\ (\mathrm{stat}) \pm 0.037\ (\mathrm{syst})$$
$$R(X_{\tau/\mu}) = 0.222 \pm 0.027\ (\mathrm{stat}) \pm 0.050\ (\mathrm{syst})$$

Systematics is largely from data-driven corrections in control regions

Combined result

$$\boldsymbol{R(X) = 0.228 \pm 0.016(\mathrm{stat}) \pm 0.036\ (\mathrm{syst})}$$

is consistent with SM 0.223±0.006, but also with measurements of $R(D^{(*)})$

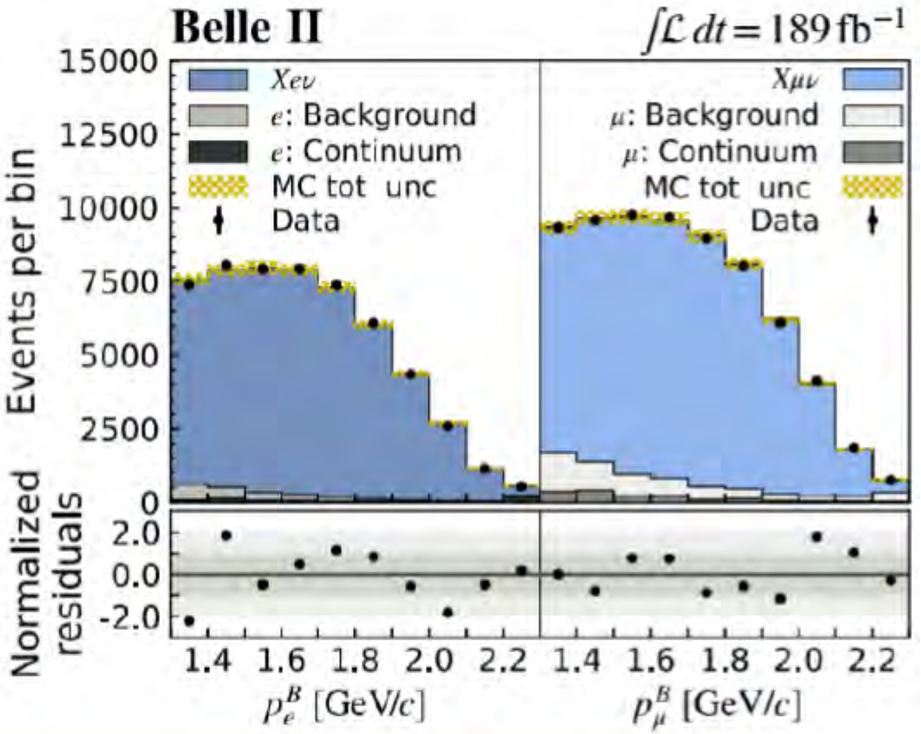
$R(X_{e/\mu})$ measurement

-The first measurement of $R(X_{e/\mu}) = \frac{\mathcal{B}(B \to X e \nu_e)}{\mathcal{B}(B \to X \mu \nu_\mu)}$ at BelleII

- -test LFU of light leptons, e and μ
- -unique measurement at BelleII with inclusive analysis

-Common analysis technique to R(X)

- -hadronic tag with a signal lepton
- -extract signal from high lepton momentum
- -constraint continuum BG by using beam energy shifted (off-resonance) data



-Result:

$$R(X_{e/\mu}) = 1.007 \pm 0.009(\mathrm{stat}) \pm 0.019(\mathrm{syst})$$

major systematics: lepton identification

World leading result. In agreement with SM

Run Plan 2024-26

Fiscal year	4	5	6	7	8	9	10	11	12	1	2	3
2021	2021b							2021c				2022a
2022	2022b			LS1								
2023									2023c	①	2024a	
2024	2024b			③			2024c			②		2025a
2025	2025b							2025c		①	2026a	
2026	2026b							2026c		①	2027a	

Assumption: 7 months operation per fiscal year with sufficient budget

① Pause of operation for new year holidays instead of a usual winter shutdown
(decided to try it first in FY2023; to be discussed for FY2025 and beyond)

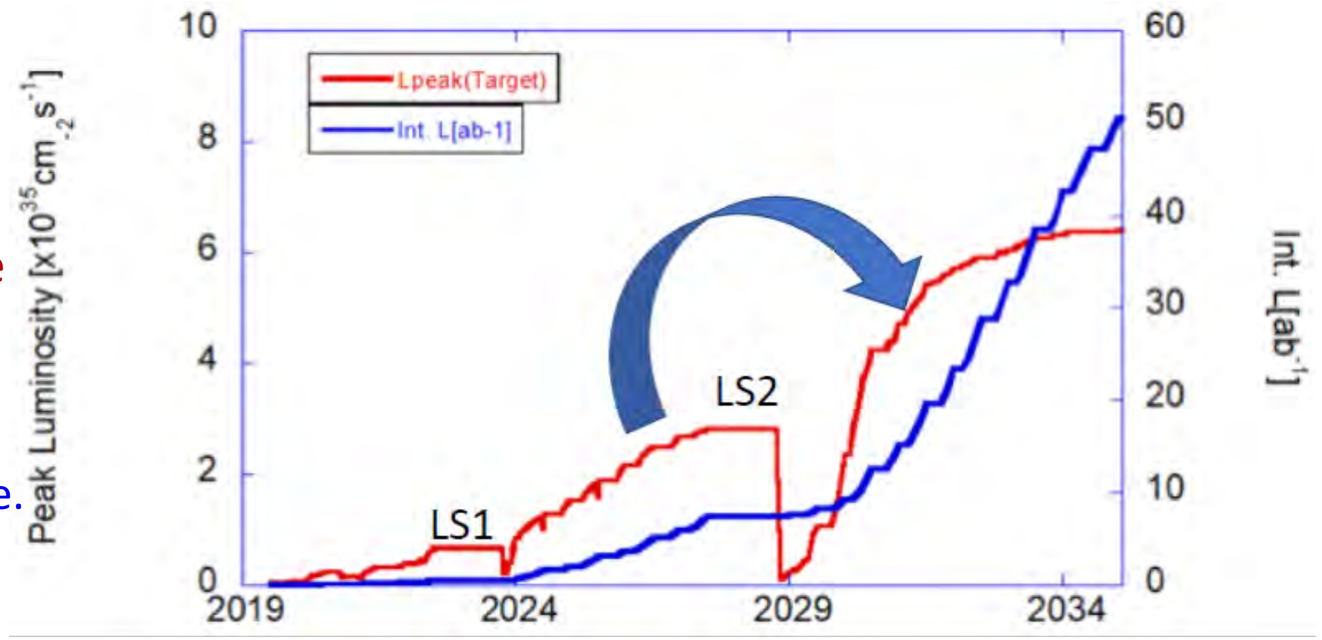
② Power restriction due to renewal of the central electric power substation
(already decided)

③ Renovation work of the roof of Tsukuba Hall in parallel to the operation
(under discussion → We are asked to give the green light by Jun 9.)

Prospettive di upgrade di macchina e di rivelatore

Nel Run II SuperKEKB dovrebbe raggiungere
$L_{peak} = 2.4 \times 10^{35}$ cm^{-2} s^{-1}.

Per poter integrare 50 ab^{-1} è necessario raggiungere
$L_{peak} = 6 \times 10^{35}$ cm^{-2} s^{-1}



- ridisegno della regione di interazione
- forse un upgrade di tutto il sistema di iniezione.

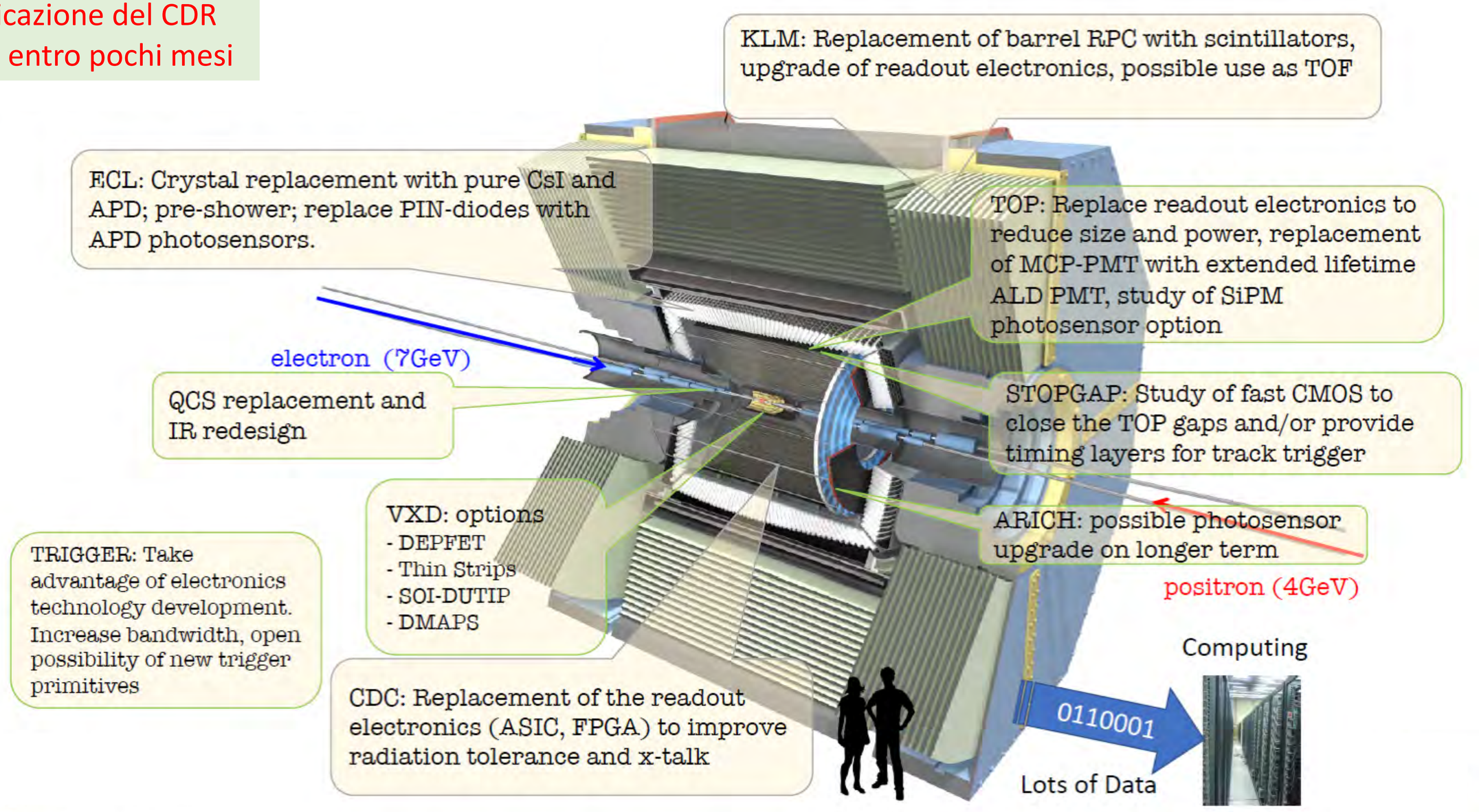
Il run 2024 fornirà maggiori indicazioni sugli interventi necessari

<u>Upgrade anche del rivelatore con tre obiettivi di fondo:</u>

- Tollerare i fondi macchina nel run ad alta luminosità
- Migliorare le performance in modo da produrre più fisica per ab^{-1}
- Essere in grado di adattare il detector a possibili cambi di IR

Idee ed R&D in discussione per l'upgrade di Belle II

Pubblicazione del CDR attesa entro pochi mesi



Upgrade: opzioni sul tavolo e attività in corso/programmate

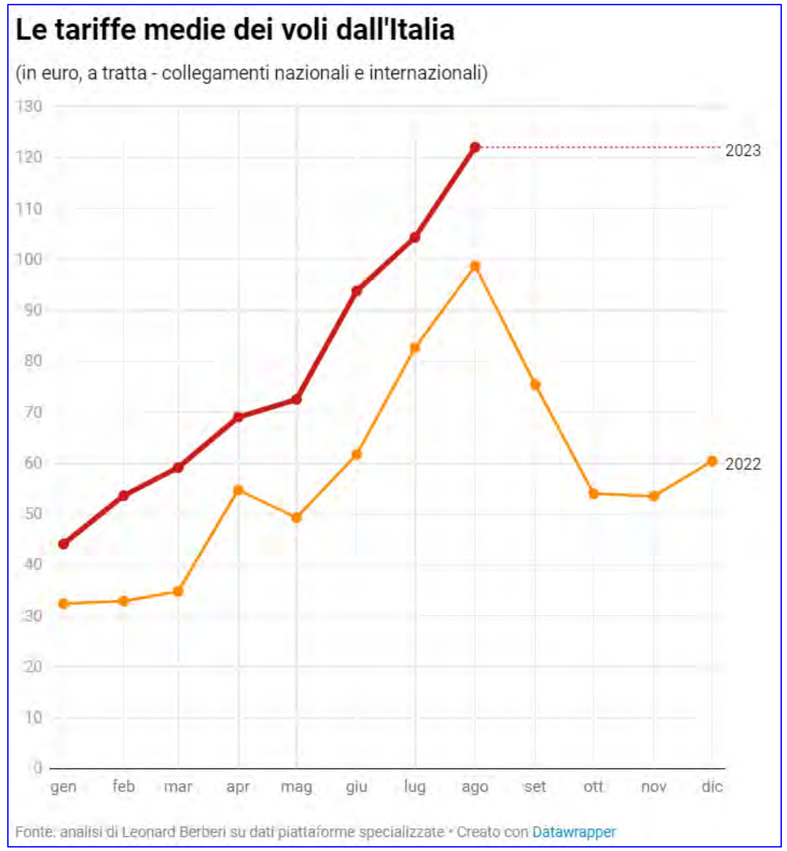
(vedi slides di F.Forti alla CSN1 di maggio)

	Subdector	Function	upgrade idea		time scale
PI	PXD	Vertex Detector	2 layer installation		now
			~~new DEPFET~~		~~medium-term~~
	SVD	Vertex Detector	thin, double-sided strips, w/ new frontend		medium-term
	PXD+SVD	Vertex Detector	all-pixels: SOI sensors		medium-term
			all-pixels: DMAPS CMOS sensors		medium-term
	CDC	Tracking	upgrade front end electronics		short/medium-term
			replace inner part with silicon	(all silicon ?)	medium/long term
			~~replace with TPC w/ MPGD readout~~		~~long-term~~
PD-TO	TOP	PID, barrel	Replace conventional MCP-PMTs		now
			Replace not-life-extended ALD MCP-PMTs	SiPM Option	medium-term
			STOPGAP TOF and timing detector		long-term
	ARICH	PID, forward	replace HAPD with Silicon PhotoMultipliers		long-term
			replace HAPD with Large Area Picosecond Photodetectors		long-term
PG-NA	ECL	γ, e ID	add pre-shower detector in front of ECL		long-term
			Replace ECL PiN diodes with APDs		long-term
			Replace CsI(Tl) with pure CsI crystals		long-term
RM3-LNF	KLM	K_L, μ ID	replace 13 barrel layers of legacy RPCs with scintillators		medium/long-term
			on-detector upgraded scintillator readout		medium/long-term
			timing upgrade for K-long momentum measurement		medium/long-term
	Trigger		firmware improvements		continuos
	DAQ		PCIe40 readout upgrade		now
			add 1300-1900 cores to HLT		short/medium-term

future

TS In addition: RMBA (Radiation Monitoring and Beam Abort).
Improve machine monitoring and protection against high radiation events

Non è aumentato solo il costo dell'energia…….



Il «mese-persona» al KEK è stato tradizionalmente valutato 5.5 k€ pari a 3.9 k€ di diaria + 2 viaggi A/R a 800 € l'uno.

Nel compilare i preventivi abbiamo chiesto ai referees di considerare il costo medio dei voli a 1.3 k€, che porterebbe il «mese-persona» a 6.5 k€.

Purtroppo per i viaggi in programma ad ottobre il costo medio dei biglietti si avvicina ormai a 2.0 k€ !!!

Se la CSN1 decide di continuare a calcolare il mese-persona al KEK come in passato (5.5 k€), configura implicitamente un taglio del 15% delle richieste, che con i costi di ottobre è in realtà un taglio effettivo del 27% sui costi reali.

In sintesi:

- Le attività di LS1 procedono come previsto e si punta alla ripartenza di SuperKEKB l'11 dicembre

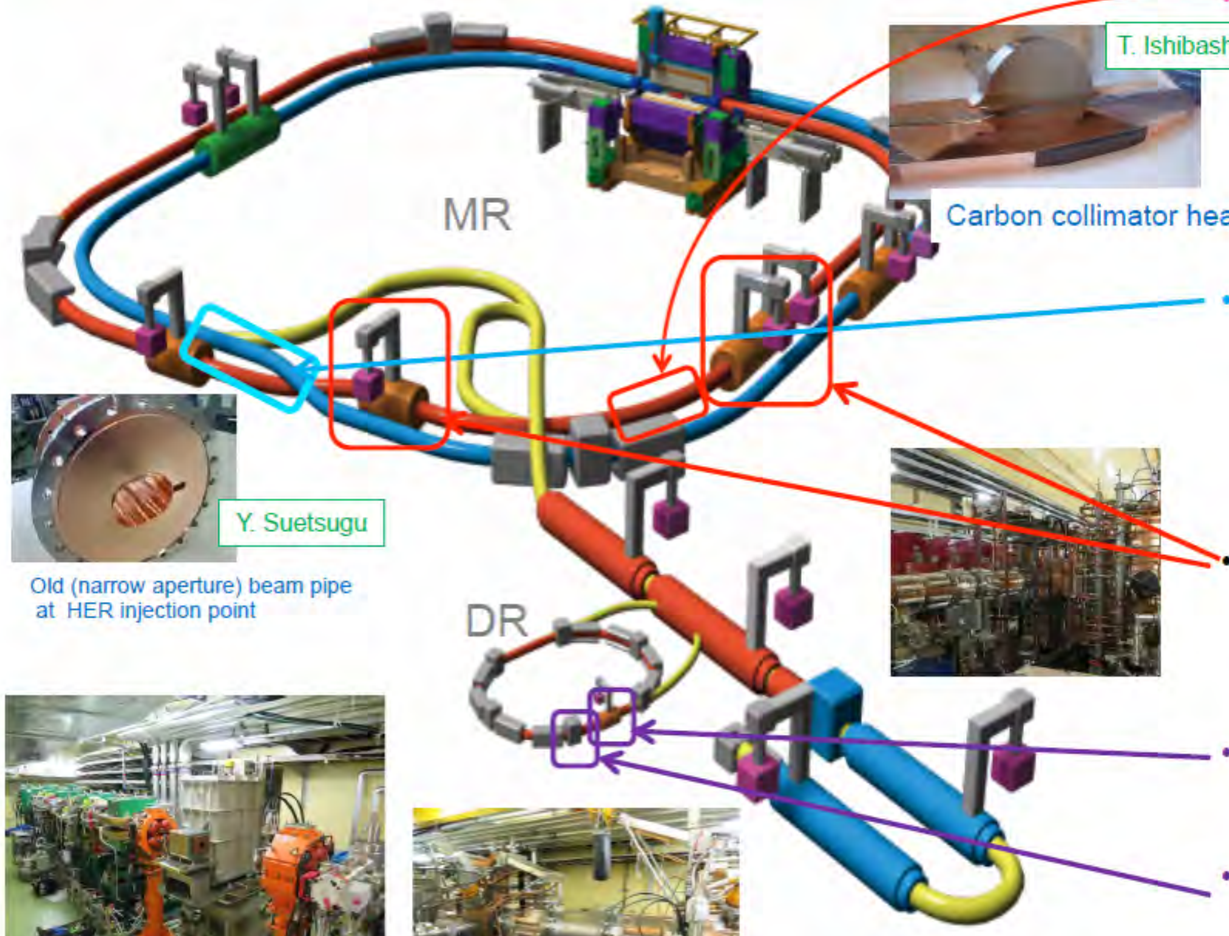
- Nel 2024 si prevedono 8.5 mesi di run. Previsti anche 7 mesi di run sia nel 2025 che nel 2026. Obiettivo integrare $O(10)$ ab^{-1}. Successivamente LS2 per upgrade verso alta lumi.

- L'attività di analisi dati e miglioramento delle performance è molto intensa ed ha prodotto numerosi risultati competitivi o unici negli ultimi 2 anni. Rate di pubblicazioni in forte crescita.

- Il progetto di upgrade del rivelatore sta diventando più chiaro nel caso di fisica e nelle tecnologie. CDR quasi pronto.

Backup slides

Other Major Works in MR during LS1



T. Ishibashi

Carbon collimator head

Y. Suetsugu

Old (narrow aperture) beam pipe at HER injection point

DR Ext. kicker


DR RF section

- **Robust collimator head (LER)**
- As countermeasures against collimator destruction due to kicker-pulser misfiring
  - Replacement with carbon head of horizontal collimator D06H3
  - Relocation from D06H1 to D06H4
  - Carbon head production : ~ March 2023 (done)
  - Head replacement : Spring ~ Summer 2023
  - Collimator relocation : Spring ~ Summer 2023
- **New beam pipes at HER injection point for wide aperture**
- For injection efficiency improvement
  - Beam pipe design at HER injection is changed for wider aperture & New BPM will be applied for precise measurement of injected beam
  - New beam pipe production : ~ March 2023 (done)
  - Beam pipe replacement : now ~ Summer 2023
  - Septum baking : ~ Summer 2023?
- RF cavity modification and replacement (LER) …..Done!
- For stable operation with larger beam current
  - Modification : Input coupler replacement, cooling power enhancement, coaxial line modification, etc. (done)
  - Cavity replacement (D05A) : January ~ February 2023 (done)
- Vacuum seal replacement at RF section (DR).....Done!
- For pressure reduction
  - Elastomer gaskets were replaced with metal gaskets for dummy pipe connections.(done)
- DR Extraction kicker power supply modification and repair (DR)
- For stable operation
  - Modification : December 2022 ~ August 2023
- And so on…

LS1 detailed schedule. Target: start Run2 on dec. 11th

Task Name	Dura...	Start	Finish
VXD P4 commissioning	7.5d	07/05/23	07/14/23
VXD P4 finalizing	9d	07/14/23	07/28/23
PXD Services Installation Top Of Belle	5d	07/18/23	07/24/23
SVD P4 cleanup after VXD commissioning	12.5d	07/12/23	07/31/23
VXD P4 installation	67d	06/21/23	10/02/23
VXD P4 outer installation fwd	25d	06/21/23	07/27/23
VXD P4 outer installation bwd	26.5d	06/21/23	07/28/23
VXD installation	0	07/28/23	07/28/23
installation of new VXD	2d	07/28/23	08/01/23
VXD P4 inner installation fwd	22.5d	08/01/23	09/07/23
VXD P4 inner installation bwd	22.5d	08/01/23	09/07/23
VXD P4 system test	16d	09/08/23	10/02/23
fwd Endcap works (Other FWD works prohibitte	14d	09/13/23	10/03/23
bwd Endcap insertion test for VXD cabling	5d	09/08/23	09/14/23
Return KLM chimney cover	2d	09/19/23	09/20/23
push in QCSR+QCSL magnet	4d	10/04/23	10/10/23
QCS works after QCS insertion	43d	10/06/23	12/08/23
install magnets fwd+bwd	19d	10/06/23	11/02/23
Installation of FPGA SEU monitor on QCS	5d	11/06/23	11/10/23
Endcap fwd insertion	23d	10/11/23	11/13/23
Endcap bwd insertion	18d	10/13/23	11/08/23
close Iron Yoke	5d	11/14/23	11/20/23
Additional PE shield in Endyoke	2d	11/21/23	11/22/23
concrete shield installation	5d	11/24/23	11/30/23
completion of IR construction	0	11/30/23	11/30/23
Run2 beam ready	0	12/08/23	12/08/23