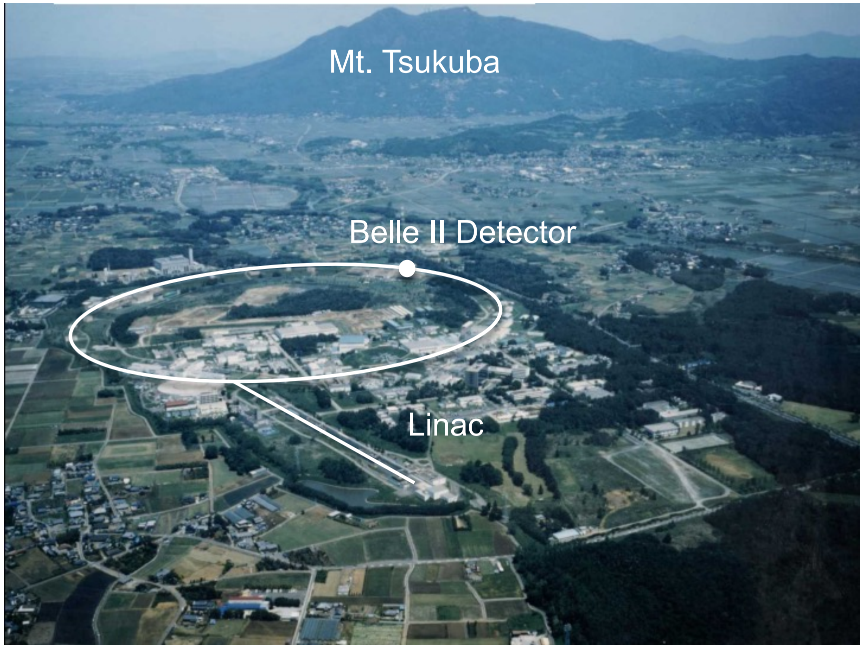
L'esperimento Belle II a SuperKEKB

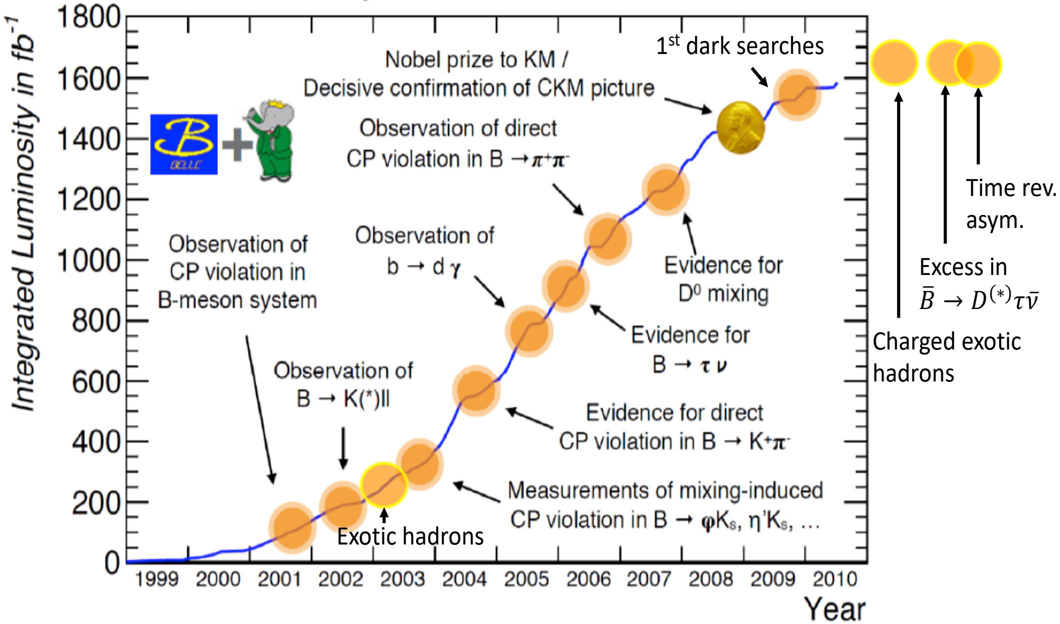
Mario Merola

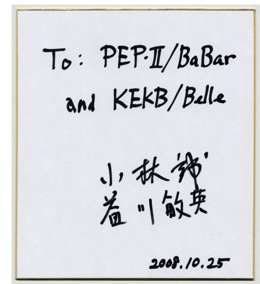
Riunione GR1

12 gennaio 2023

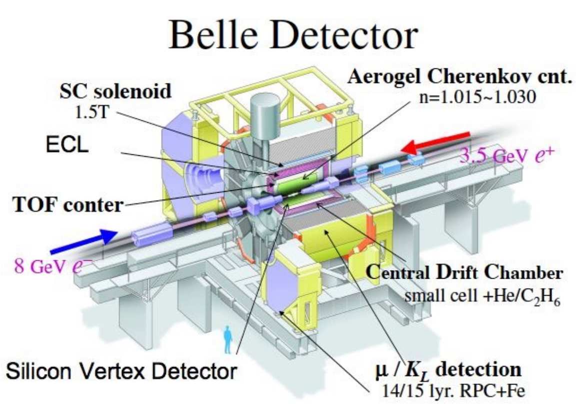


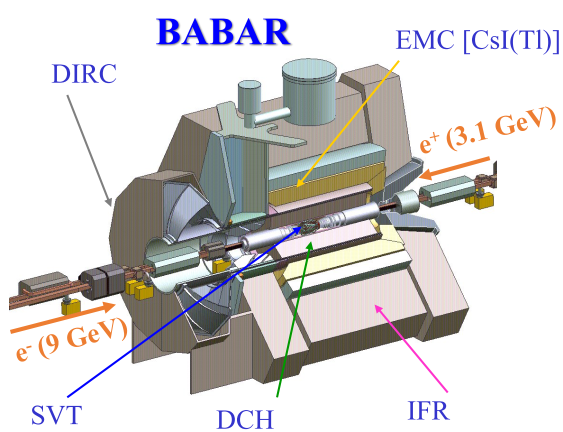
Babar and Belle achievements





Kobayashi, Maskawa nobel prize in 2008





Successful experimental program
Established CP violation in B system and remarkable consistency of the CKM mechanism of the SM

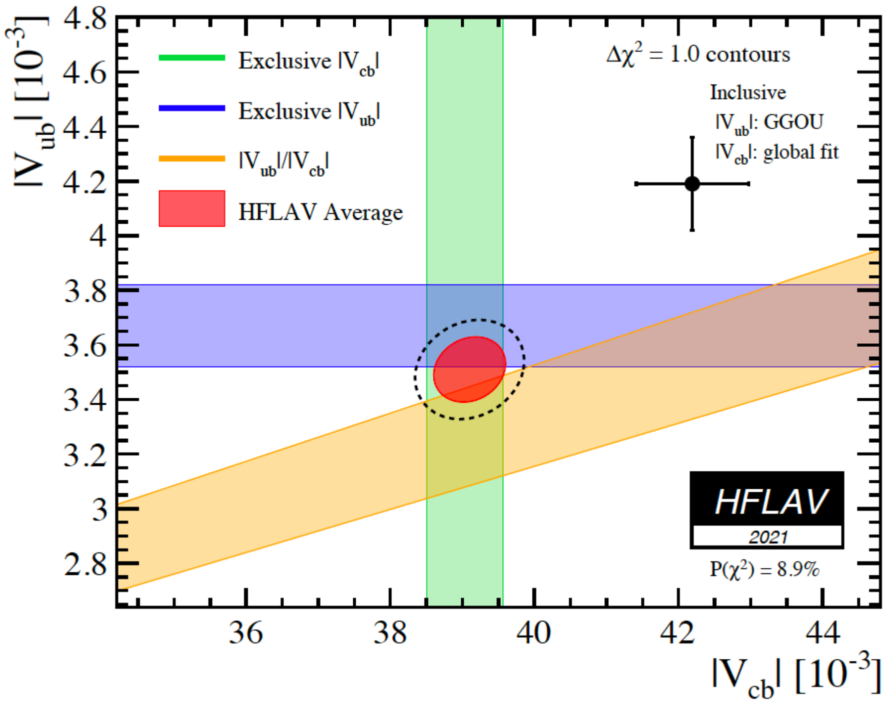
Hot topics (1)
Inclusive and exclusivs V_{xb} determinations

- Current precision is **1-2% on $|V_{cb}|$** and **3-4% on $|V_{ub}|$**

- **Tension** between inclusive and exclusive determinations: ~3σ for both $|V_{cb}|$ and $|V_{ub}|$

- $X_c l\nu$ decays are a clear test of the SM LFU: **NP** (charged Higgs in 2HDM models or Leptoquarks) **can affect the BR and $|V_{cb}|$**

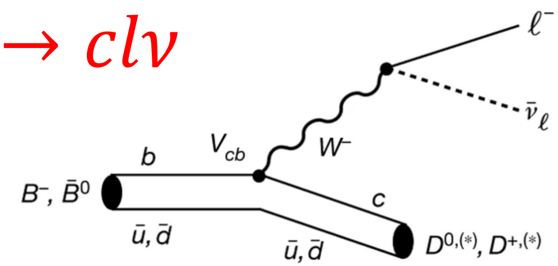
hflav.web.cern.ch



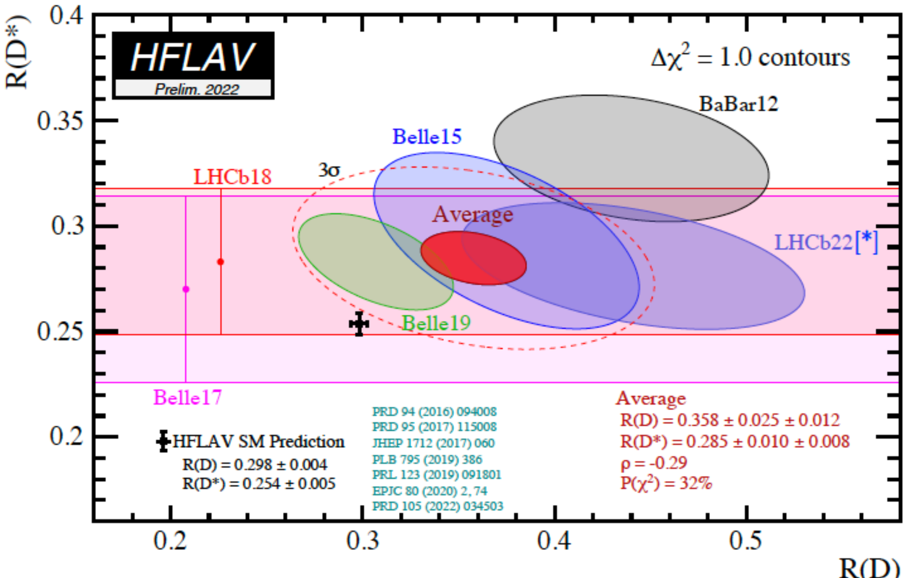
New physics or theoretical issue ?

Hot topics (2): LFV in B decays

$b \to c l \nu$

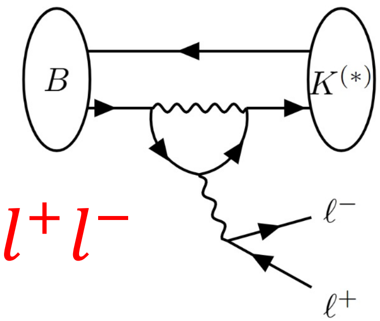


$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau\nu)}{\mathcal{B}(B \to D^{(*)}\ell\nu)}$$

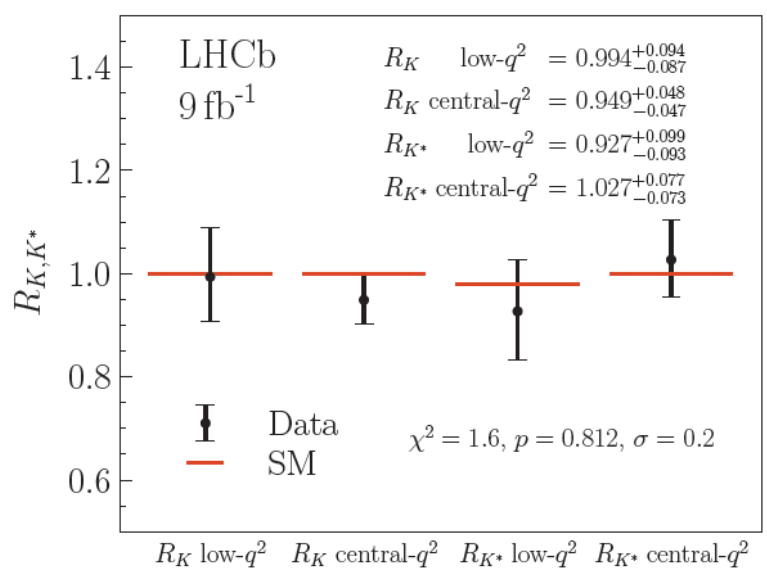


[*] CERN seminar

$b \to s l^+ l^-$

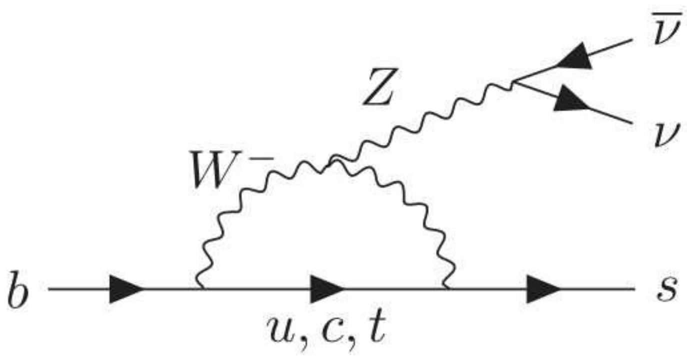


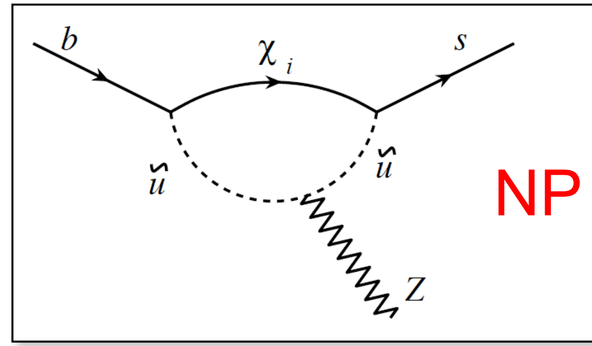
$$R(K) = \frac{\mathcal{B}(B^+ \to K^+\mu\mu)}{\mathcal{B}(B^+ \to K^+ee)}$$



arXiv:2212.09153v1

Hot topics (3): rare decays

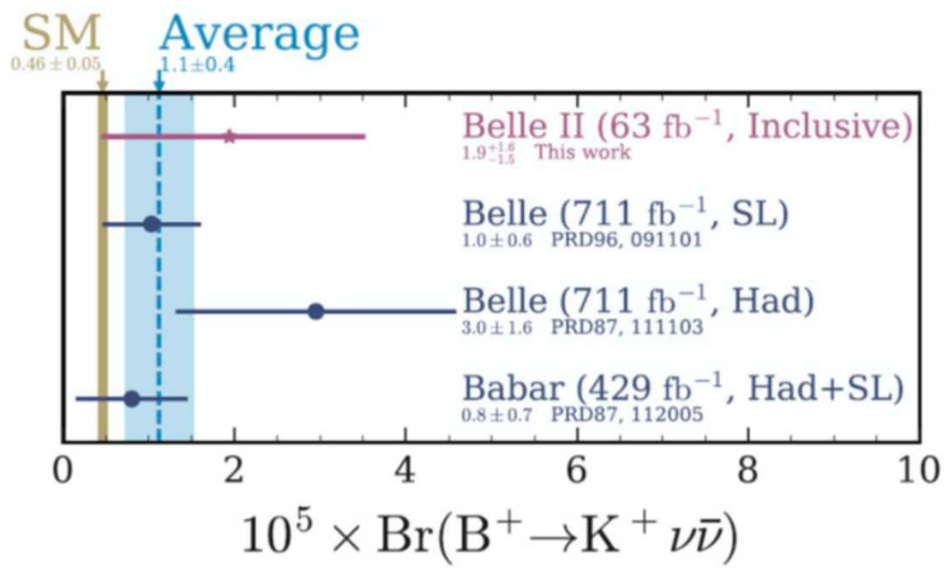




$$B \to K^{(*)} \nu \bar{\nu}$$

FCNC, with BR ~ 10^{-6}

Update coming soon !

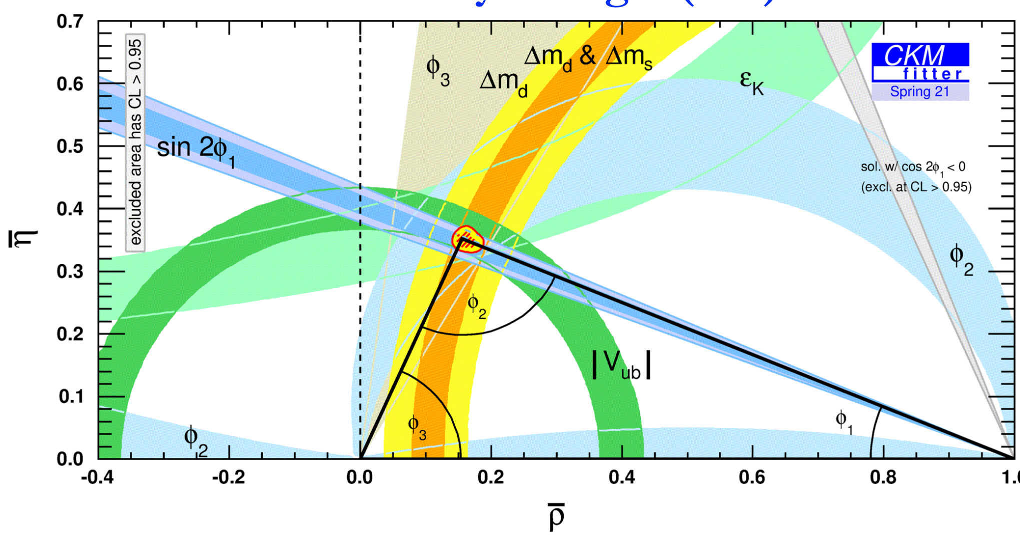


Phys.Rev.Lett. 127 (2021) 18, 181802

Belle II physics program

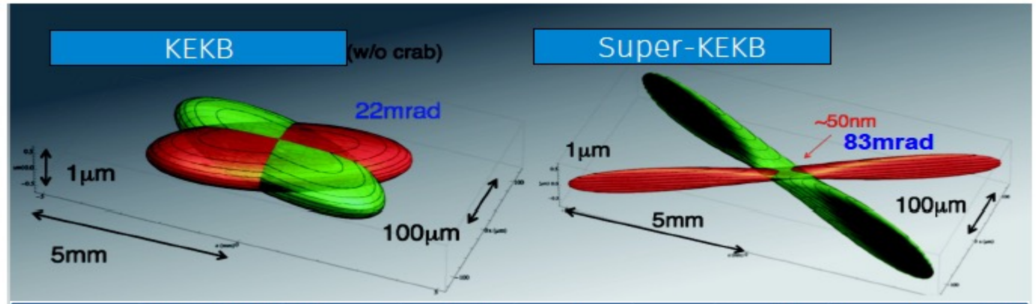
- CPV in B decays, **UT angles** ($B \to J/\psi K^0$, $K^0\pi^0\gamma$, $K\pi$)
- (Semi)leptonic B decays, **UT sides** ($B \to D^{(*)}l\nu$, $\pi l\nu$, $\tau\nu$, $\mu\nu$)
- Rare B decays ($B \to K^{(*)}\nu\nu$, $X_s\gamma$, $X_s ll$, $\gamma\gamma$)
- Charm physics ($D \to l\nu$, mixing, CPV)
- LFV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

Unitarity triangle (UT)



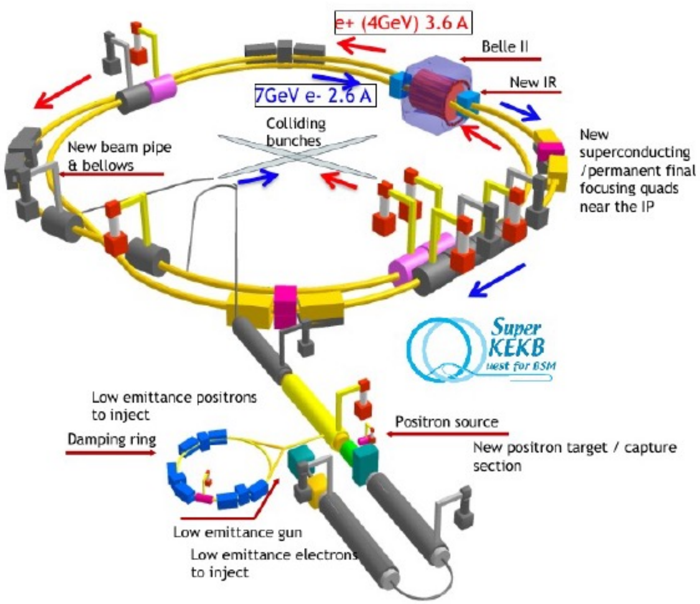
SuperKEKB

- Asymmetric energy e^+e^- collider
- Situated at KEK (Tsukuba, Japan), upgrade of KEKB

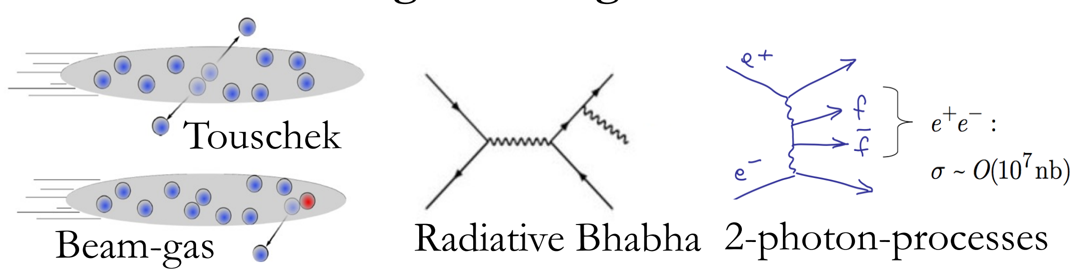


	Energy (GeV) LER/HER	β_y^* (mm) LER/HER	ε_x (nm) LER/HER	ξ_y LER/HER	φ (mrad)	I_{beam} (A) LER/HER	Luminosity ($cm^{-2}s^{-1}$) x 10^{34}
KEKB Achieved	3.5/8.0	5.9/5.9	18/24	0.13/0.09	11	1.6/1.2	2.11
SuperKEKB	4.0/7.0	0.27/0.3	3.2/2.4	0.09/0.09	41.5	2.8/2.0	65

factor 20 factor 1.5



Higher backgrounds



- Radiation damage
- Occupancy in inner detectors
- Fake hits and pile-up

Belle II Detector

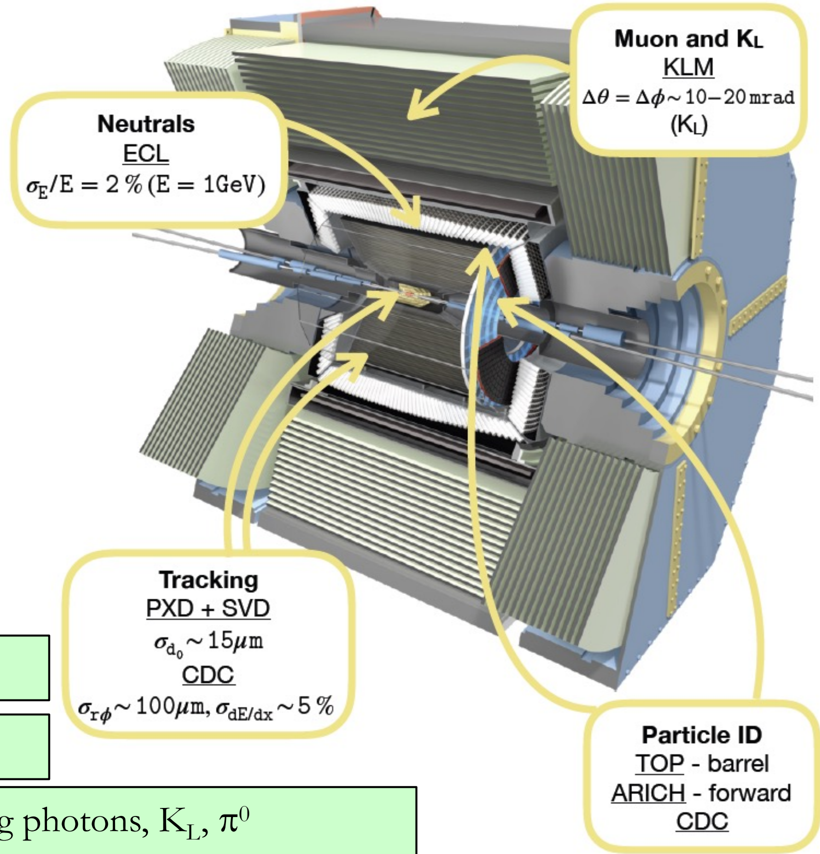
- Good momentum and vertex resolution
- Well-known initial state and large acceptance
- Excellent calorimetry
- Sophisticated particle ID

  K/π separation (ε~90% @ 5-10% fake)

  Lepton identification

  μ/π (ε~90% @ 7% fake)

  e/π (ε~86% @ <1% fake)



Unique capabilities

Exactly 2 quantum correlated B mesons at Υ(4S)

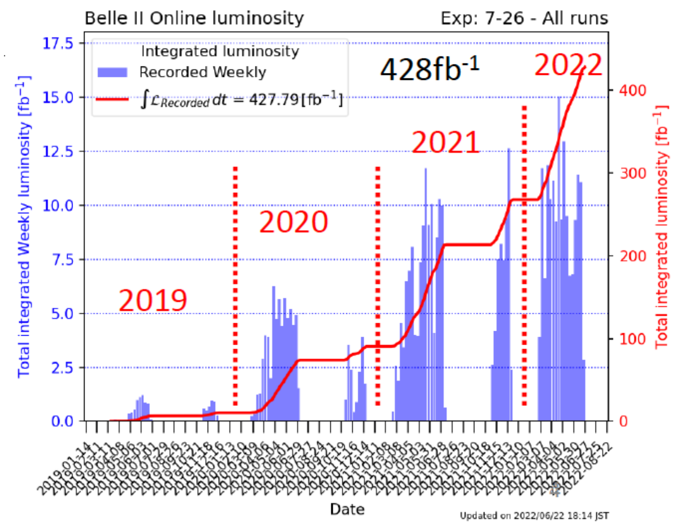
No trigger bias – almost 100% for B pairs

Excellent efficiency and resolution in tracking as well as in detecting photons, K_L, π^0
→reconstruction of intermediate resonances
→Dalitz plot studies

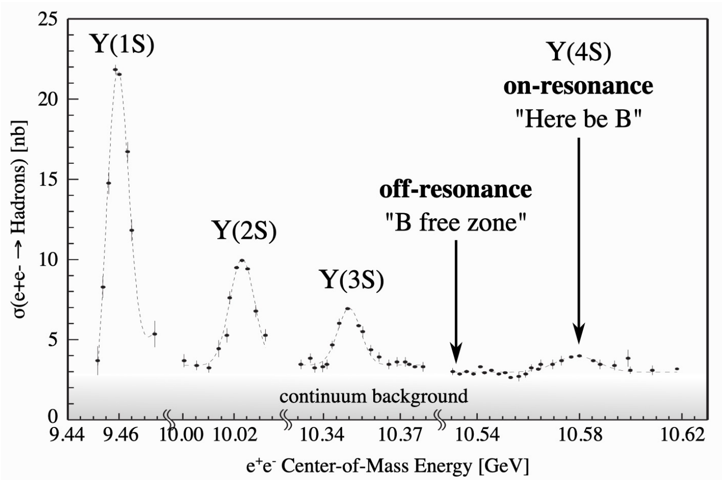
Clean environment (w.r.t. to hadron machines) allows "full interpretation" of the event
→ powerful tool for physics with missing energy (many neutrinos) or fully inclusive analyses

Large sample of B, D, and t with low background

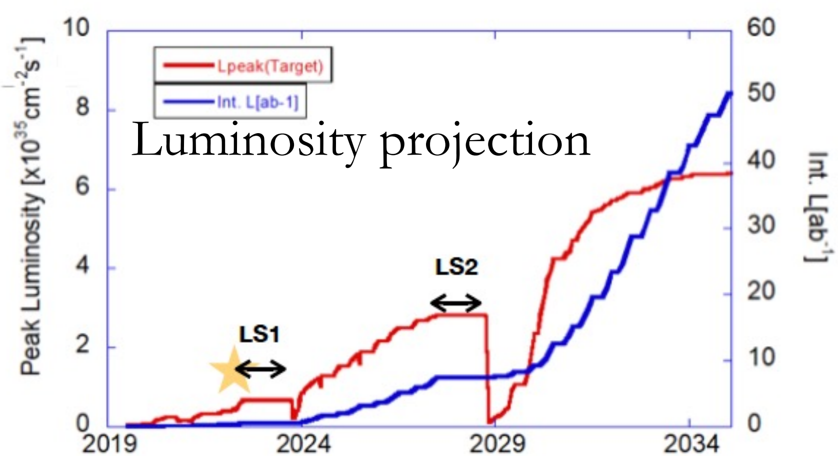
Luminosity and projections



L_{int} = 424 fb^{-1} ~ Babar dataset



- 85% taken at Υ(4S) peak – **BB pairs**
- 10% taken 60 MeV below Υ(4S) – **cont (qq, ll, 2γ)**
- 5% taken around 10.75 GeV - **spectroscopy**



A long journey …

- 1st Long shutdown (LS1) in 2022-2023 (PXD, beam pipe, TOP)
- 2nd Long shutdown (LS2) in ~2028 (QCS, RF)
- The target integrated luminosity is **50 ab^{-1} by ~2034**

Recent Physics Publications

Observation of $e^+e^- \to \omega\chi_{bJ}$ and search for $X_b \to \omega\Upsilon(1S)$ at $\sqrt{s}$ near 10.75 GeV
Submitted to PRL, arXiv:2208.13189

Measurement of the Ω_c^0 lifetime at Belle II
PRD(L) (accepted), arXiv:2208.08573

Search for an invisible Z′ in final states with two muons and missing energy at Belle II
Submitted to PRL, arXiv:2212.03066

Search for lepton-flavor-violating τ decay to a lepton and invisible boson at Belle II
Submitted to PRL, arXiv:2212.03634

Search for a dark photon and an invisible dark Higgs boson in μ+μ− and missing energy final states with the Belle II experiment
PRL (accepted), arXiv:2207.00509

Combined analysis of Belle and Belle II data to determine the CKM angle ϕ3 using B+→D0(K0Sh+h−)h+ decays
JHEP 02 **2022**, 063 (2022)

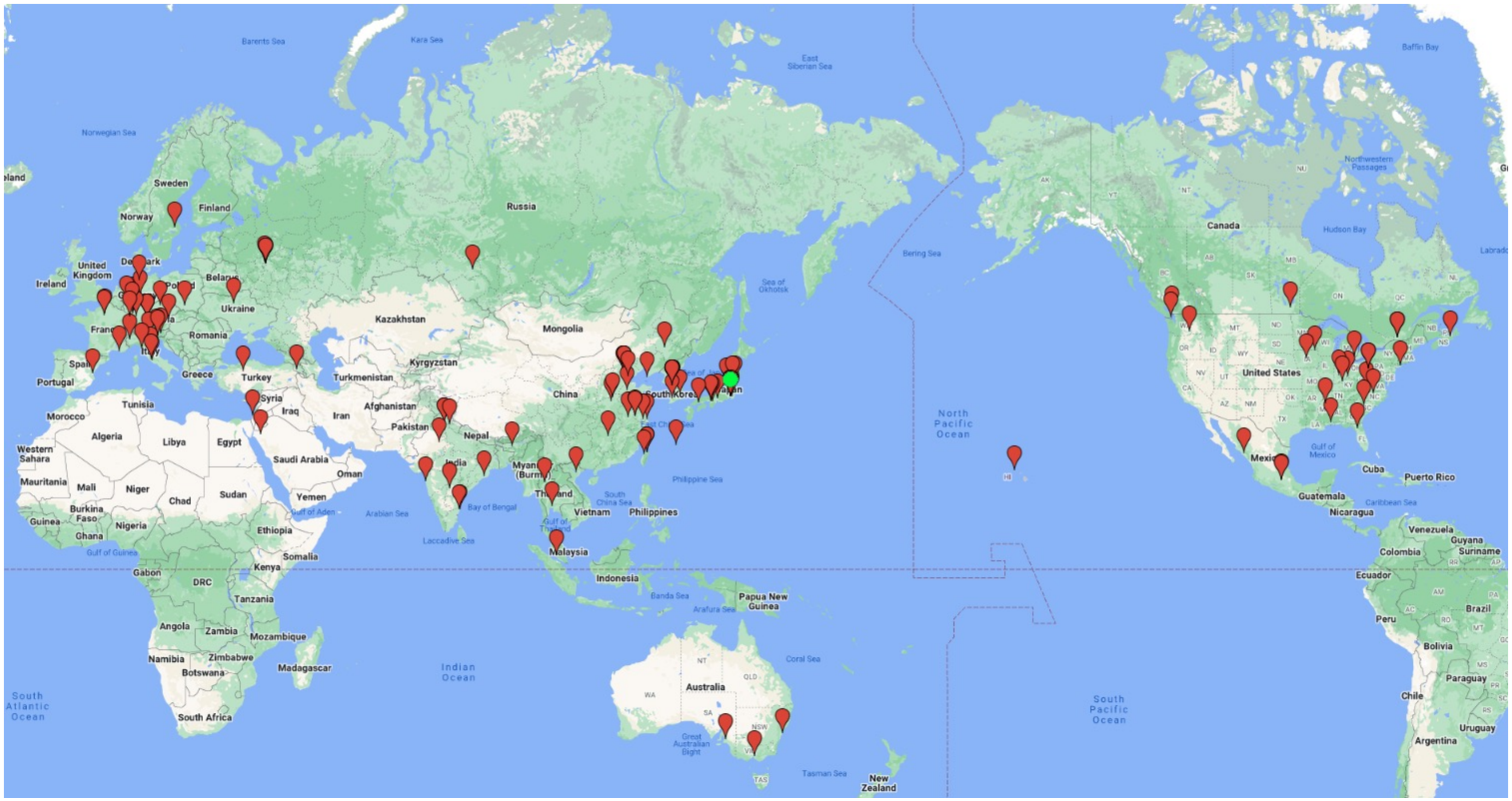
Measurement of lepton mass squared moments in $B \to X_c l^+ \bar{\nu}_l$ decays with the Belle II experiment
Submitted to PRD, arXiv:2205.06372

Search for $B \to K^+ \nu\bar{\nu}$ using an inclusive tagging method at Belle II
Phys Rev Lett **127**, 181802

+ many conference contributions with physics measurements assessing the experiment readiness/ performances in doing real physics analysis

Standard model anomalies: lepton flavour non-universality, $g-2$ and W-mass
A. D'Alise, G. De Nardo, M. G. Di Luca, G. Fabiano, D. Frattulillo, G. Gaudino, D. Iacobacci, M. Merola, F. Sannino, P. Santorelli, N. Vignaroli
https://doi.org/10.1007/JHEP08(2022)125

Belle II collaboration



Belle II: ~1160 collaborators, 124 institutions, 27 regions/countries
tra cui 8 sezioni INFN, 108 membri

Anagrafica INFN 2022

Guglielmo De Nardo	(PO)	80%
Alberto Aloisio	(PO)	30%
Marcello Campajola	(AR)	100%
Francesco Di Capua	(PA)	30%
Giovanni Gaudino	(PhD)	100%
Raffaele Giordano	(PA)	50%

Mario Merola	(PA)	80%
Marco Mirra	(R)	40%
Guido Russo	(PO)	70%*
Antonio Ordine	(PT)	20%
Silvio Pardi	(PT)	60%*

TOTALE: 6.6 FTE

*percentuali su altre sigle di progetti con attività riconducibili a Belle II sono state incluse

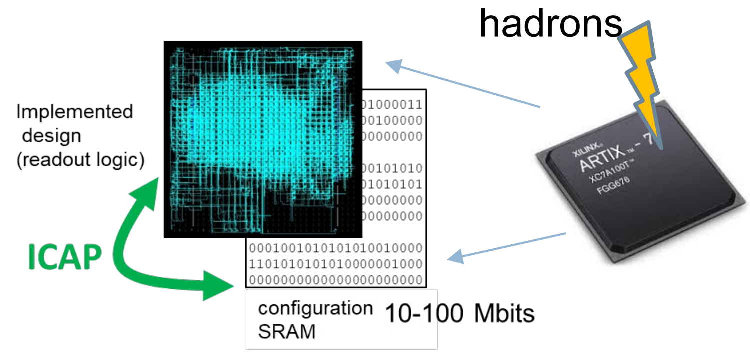
Calorimetro elettromagnetico
Mantenimento e operations del sottosistema (De Nardo, Aloisio, Campajola, Di Capua, Giordano, Merola, Mirra)
Sistema di monitoraggio temperatura e umidità (Aloisio, Di Capua, Giordano)
Studio background di fascio
Dosimetria con film radiocromici (installati calorimetro e vertice) sviluppo e installazione sistema di lettura on-line (Di Capua)
Studio rad-hardness di FPGA installati sulla beam-line e su detector (Giordano)
Calcolo
Attività di produzione di simulazioni MC (data center ReCaS/Ibisco) (Russo, Pardi)
Coordinamento dei data center italiani (Pardi)
Fisica
Analisi dati di processi leptonici del B e del dark sector (De Nardo, Merola, Campajola, Gaudino)
Misura della produzione di coppie di mesoni B (De Nardo, Merola)
Studio delle performance ricostruzione fotoni e π^0 (Gaudino, Mirra)

HIGHLIGHTS ATTIVITÀ NAPOLI

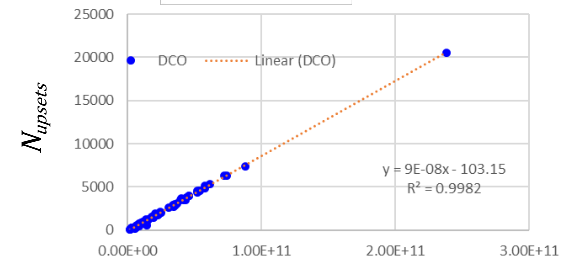
FPGA-Based Hadron Fluence Monitors

R. Giordano

- Interest of Belle II background community for single-event upset monitoring in on-detector FPGAs and neutron-related background in general
- Novel FPGA-based sensors developed in PHI experiment (CSNV)
- Irradiation tests at the TRIGA nuclear reactor of Jožef Stefan Institute (Ljubljana)
- σ(Energy, V_{DD}) characterization at Trento Institute for Fundamental Physics and Applications

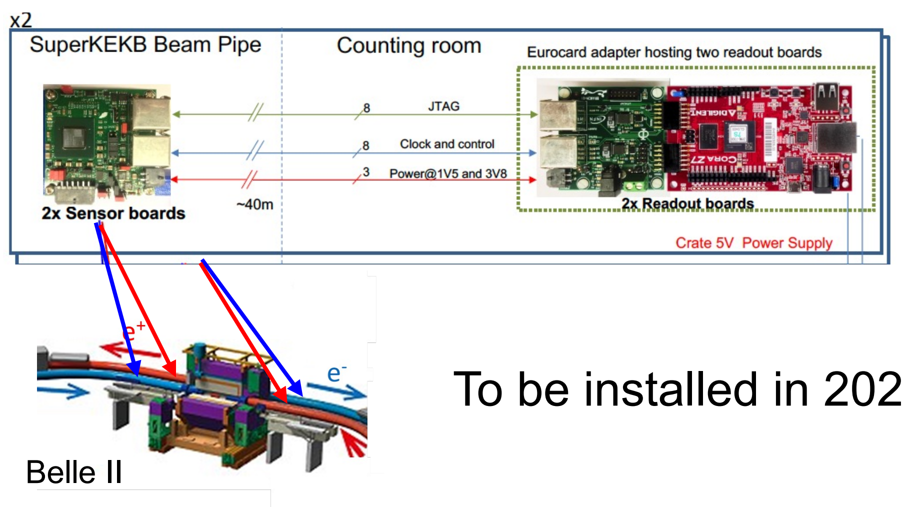


$$\Phi = \frac{N_{upsets}}{\sigma\, N_{bits}}$$



4 sensors + 4 readout boards: 2 at forward (e+/e-) plus 2 at backward (e+/e-)

Back-end server at INFN NA for data collection and web publication (Grafana)



To be installed in 2023

Attività di computing

G. Russo, S. Pardi

Milestone Italiana per il 2022: fornire il 12% de MC. Italian Share fornito: 13.3%

- **Il sito di Napoli è il primo sito della collaborazione per potenza di calcolo fornita dopo i RAW Data Center**

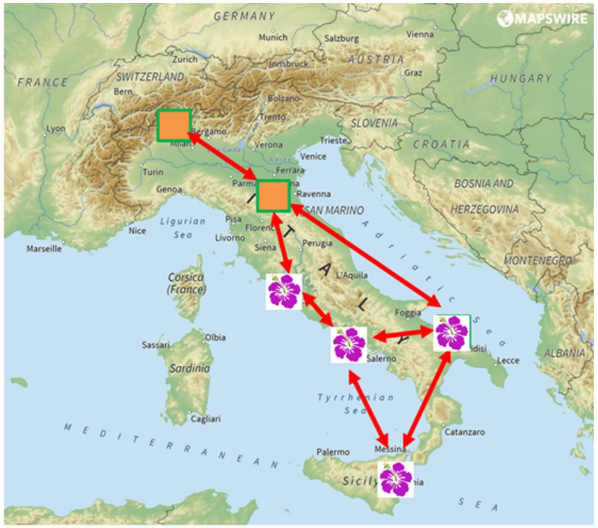
Nuovo hardware di Belle II fornito con il progetto IBISCO.

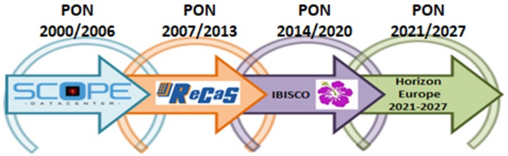
I.Bi.S.Co. (Infrastructure for Big Data and Scientific Computing)

- Napoli (INFN Unit + University Federico II)
- 10 PB of disk space - **1PB per Belle II (590TB Pledged)**
- 110 Server per HTC - **16 server renewal pledged Belle II**
- Cloud Cluster (that will be part of INFN Cloud)
- HPC Resources with GPU

Datacenter in ulteriore espansione con il PNRR.

(Guido Russo, Silvio Pardi per Belle II. Grazie Alessandra Doria, Bernardino Spisso, Michele Delli Veneri e tutto il gruppo di IBISCO per il supporto)





INFN-Napoli leader nelle nuove tecnologie

- Transizione alla token-based-authentication in sostituzione dei certificati x509
- Transizione al protocollo WebDAV al posto degli storici protocolli GridFTP/SRM
- Implementazione dei Job Multicore

Responsabilità:

Silvio Pardi - Coordinatore Italiano del Computing e Infrastructure Coordinator per Belle II

Attività performance e analisi

- Neutri (efficienza pi0 e risoluzione fotoni)
- B-counting
- Dark sector searches
- $B \rightarrow \tau\nu$

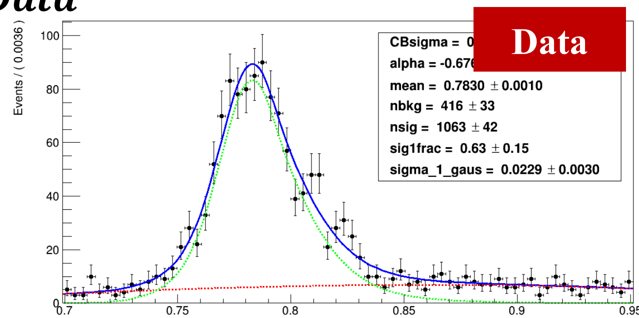
π^0 efficiency

M. Mirra

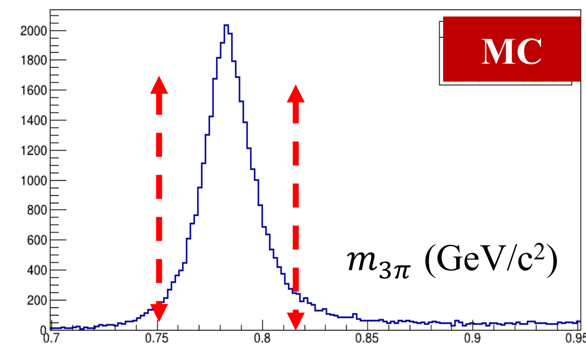
- MC/Data comparison of π^0 detection efficiency via the decay chain

$$e^+e^- \rightarrow \omega(782)\gamma_{ISR} \rightarrow \pi^+\pi^-\pi^0\gamma_{ISR}$$

- **Efficiency definition**
  - N_{π^0}: number of events with $\pi^0 \rightarrow \gamma\gamma$
  - N_{ω}: number of events with meson ω production
  - $\varepsilon_{\pi^0 MC} = \left({}^{N_{\pi^0}}/{}_{N_\omega}\right)_{MC}$ and $\varepsilon_{\pi^0 Data} = \left({}^{N_{\pi^0}}/{}_{N_\omega}\right)_{Data}$



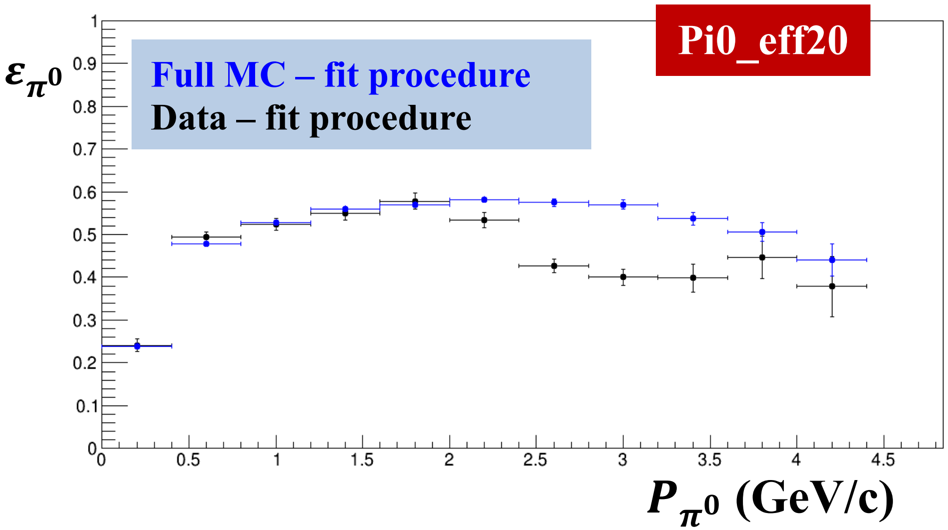
- **Two different efficiencies :**
  - Fit to $m_{3\pi}$ distribution to evaluate N_ω before and after π^0 selection
  - Count events in $m_{3\pi}$ distribution for $|m_{3\pi} - m_\omega|$ <3σ to evaluate N_ω before and after π^0 selection (signal MC)

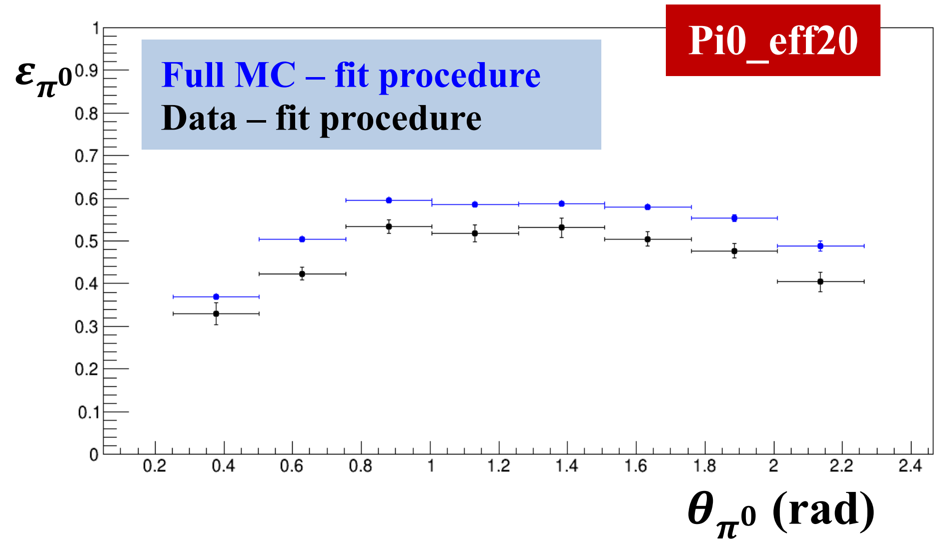


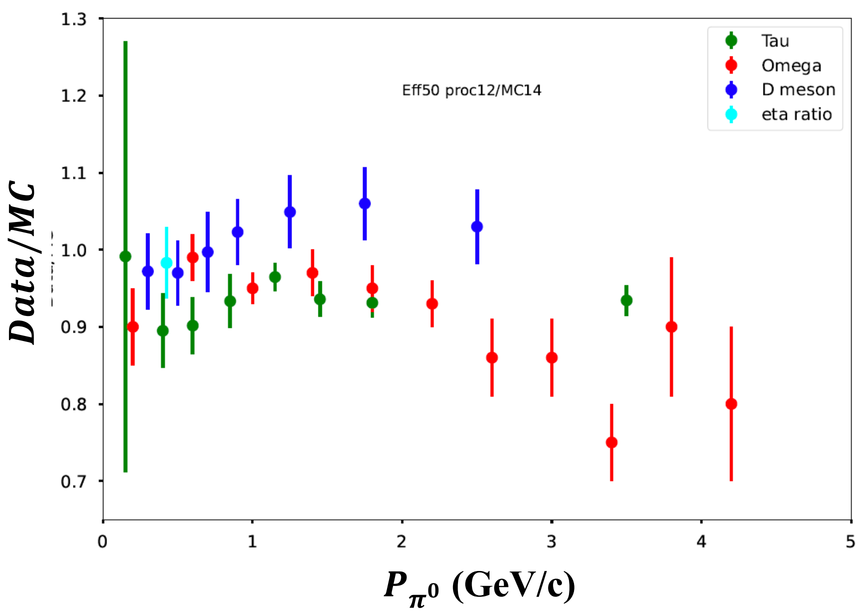
π^0 detection efficiency

M. Mirra

- ε_{π^0} can be evaluated in bin of momentum, θ and φ of the fitted π^0







$e^+e^- \rightarrow \omega\gamma_{ISR} \rightarrow \pi^+\pi^-\pi^0\gamma_{ISR}$

Complementary to other channels studied in Belle 2

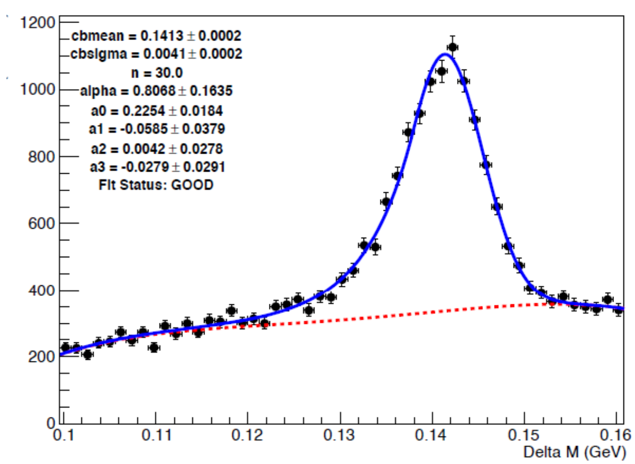
Photon resolution

G. Gaudino

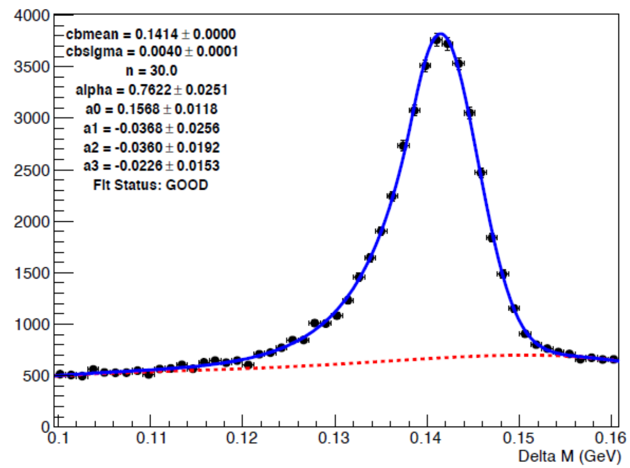
$D^{0*} \rightarrow D^0\gamma$ $D_s^* \rightarrow D_s\gamma$

This channel is optimal to study the low energy photon resolution. We can extract the photon resolution from $\Delta M = M_{D^*} - M_D$ because the tracking resolution component is negligible: $\sigma_{\mathrm{tr}}(\Delta M) \approx 0.5$ MeV.

Fit on ΔM: Crystal ball for the signal and a 3th order Chebychev polynomial for the combinatorial background.



$D^0 \rightarrow K\pi\pi\pi$



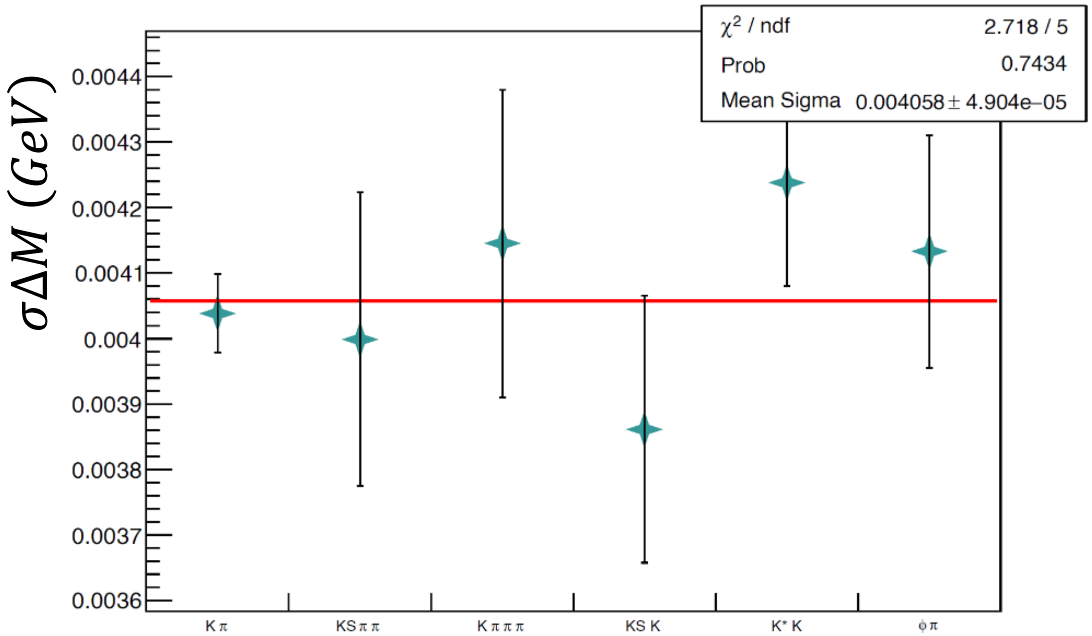
$D^0 \rightarrow K\pi$

Combining all the channels

G. Gaudino

To combine the six decay channels we computed the weighted average of the crystal ball σ

E_γ in 0.3-1.0 GeV



Low energy photon resolution (imp. for $D^* \to D\gamma$)

γ Energy (MeV)	σ_{Data}(MeV)	σ_{MCri}(MeV)	σ_{MCrd}(MeV)	Ratio MCri	Ratio MCrd
$100-200$	(4.98 ± 0.76)	(5.12 ± 0.17)	(4.91 ± 0.19)	(0.97 ± 0.15)	(1.01 ± 0.16)
$200-400$	(4.74 ± 0.13)	(4.50 ± 0.06)	(4.50 ± 0.05)	(1.05 ± 0.03)	(1.05 ± 0.03)
$400-600$	(4.16 ± 0.06)	(3.77 ± 0.02)	(3.88 ± 0.03)	(1.10 ± 0.02)	(1.07 ± 0.02)
$600-1000$	(3.69 ± 0.17)	(3.27 ± 0.05)	(3.25 ± 0.05)	(1.13 ± 0.06)	(1.14 ± 0.06)
$300-1000$	(4.09 ± 0.05)	(3.85 ± 0.02)	(3.80 ± 0.02)	(1.06 ± 0.01)	(1.08 ± 0.01)

B-counting

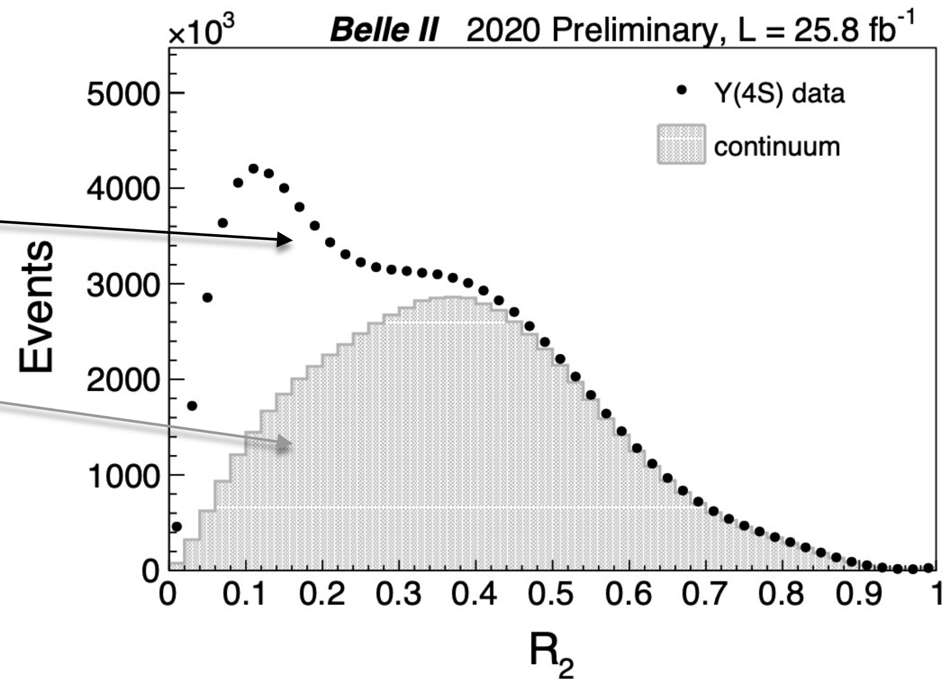
De Nardo, Merola

Motivation of B-counting

- N_{BB} important input for branching ratio measurements
- $N_{BB} = L \cdot \sigma_{BB}$ has high uncertainty due to the uncertainty on σ_{BB} (2-5%)
- Indirect measurement of σ_{BB}

Subtraction procedure

on resonance data
-
continuum
=
BB



We estimate the continuum component using off-resonance data: need to take into account the different cross sections (and efficiencies) of non-BB processes at off-resonance energy

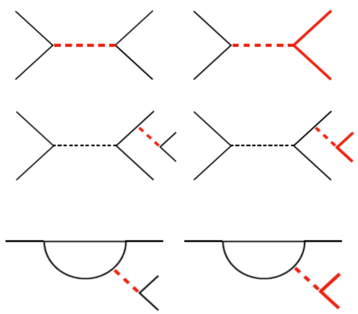
Published papers or conference notes are using our numbers

N_{BB} unc. ~ 1-1.5%

Dark Sector searches

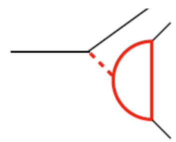
Campajola

Direct production



Directly produced in SM particle collisions or in mesons (*D, B, Υ* or other) decay

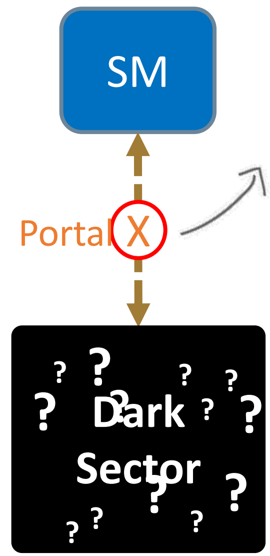
Precision physics



Deviation from SM prediction due to loop induced effects

DS mediator

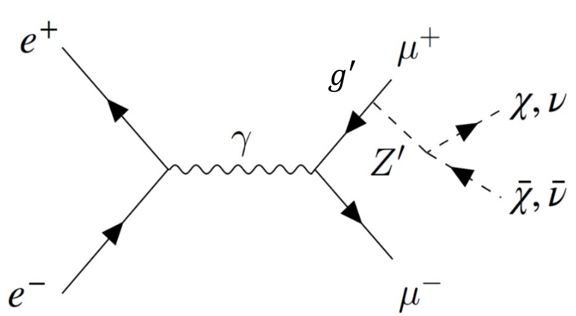
Dark matter



Non-gravitational interaction with matter

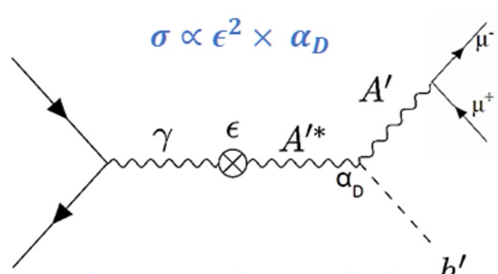
- Dark matter;
- Dark Forces;
- ……

Search for a Z' invisible decay



Dark Higgsstrahlung search

$\sigma \propto \epsilon^2 \times \alpha_D$

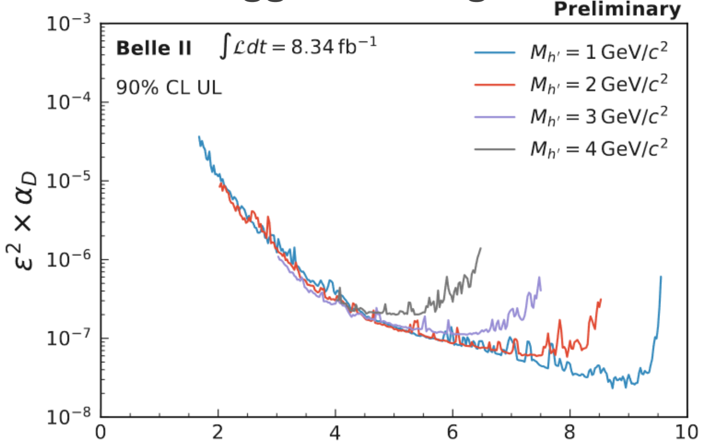


$e^+e^- \rightarrow A'^* \rightarrow h' A'$

Dark Sector searches

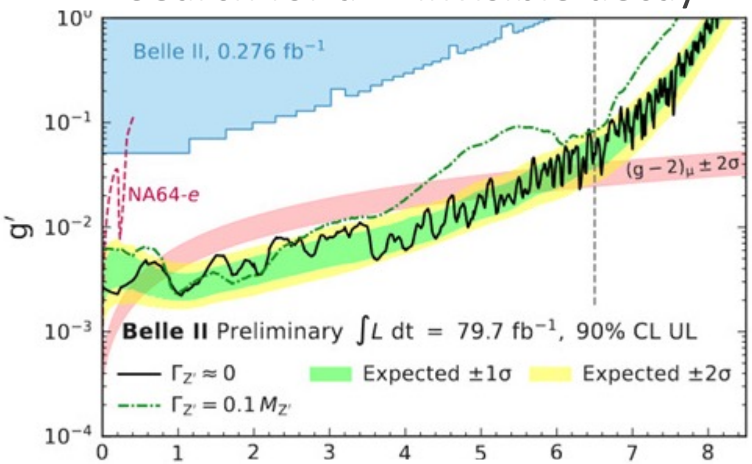
Campajola

Dark Higgsstrahlung search



dark photon mass (GeV/c^2)

Search for a Z' invisible decay



Z' mass (GeV/c^2)

Search for an invisible Z′ in final states with two muons and missing energy at Belle II
Submitted to PRL, arXiv:2212.03066

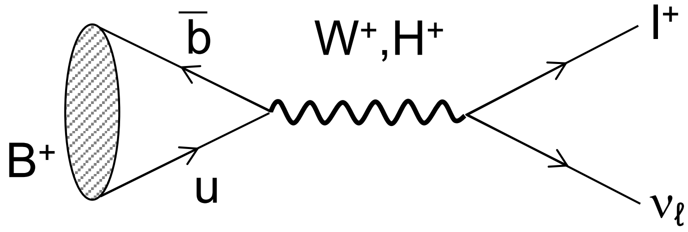
Search for a dark photon and an invisible dark Higgs boson in μ+μ− and missing energy final states with the Belle II experiment
PRL (accepted), arXiv:2207.00509

Search for an Invisibly Decaying Z′ Boson at Belle II in e+e−→μ+μ−(e±μ∓) Plus Missing Energy Final States
Phys. Rev. Lett. 124, 141801 (2020)

talk from Marcello Campajola later today

Leptonic decays

M. Aversano, G. De Nardo, G. Gaudino, M. Merola

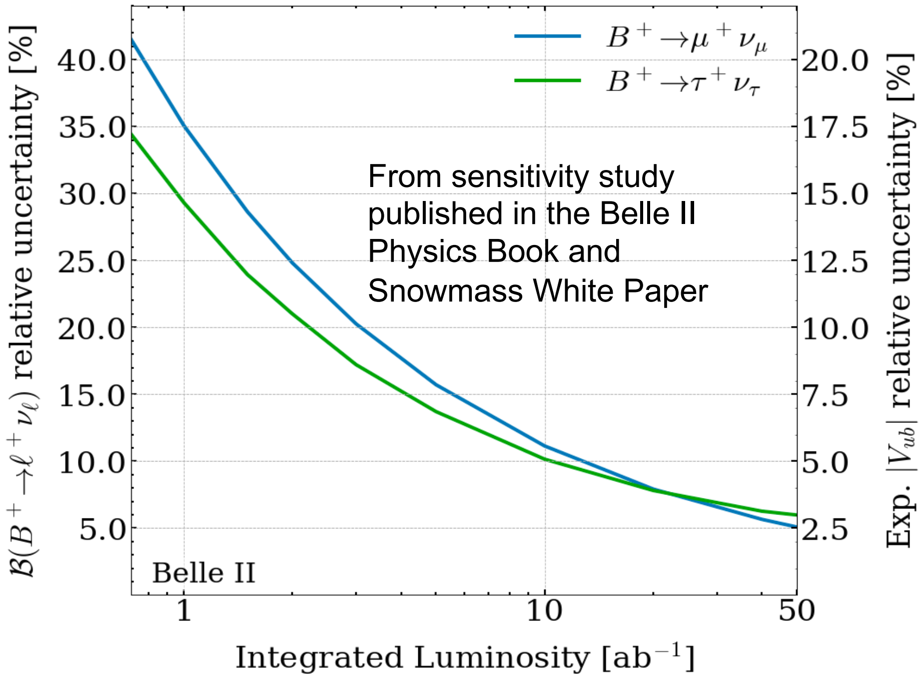


$$\mathcal{B}(B \to l\nu) = \frac{G_F^2 m_B}{8\pi} m_l^2 (1 - \frac{m_l^2}{m_B^2})^2 f_B^2 |V_{ub}|^2 \tau_B$$

$$\mathcal{B}(B \to l\nu) = \mathcal{B}(B \to l\nu)_{SM} \times r_H$$

$$r_H = (1 - \tan^2\beta \frac{m_B^2}{m_H^2})^2$$

in 2HDM type II



- Very clean theoretically, hard experimentally
- SM is helicity suppressed
- Sensitive to NP contribution (for ex: Charged Higgs)

Aiming at public Belle II result in summer 2023

talk from Giovanni Gaudino later today

Outlook

Luminosity matters

Observable	Past: 2022 Belle(II), BaBar	Soon: Belle-II 5 ab^{-1}	Target: Belle-II 50 ab^{-1}	Dream: Belle-II 250 ab^{-1}
$\sin 2\beta/\phi_1$	0.03	0.012	0.005	0.002
γ/ϕ_3 (Belle+BelleII)	11°	4.7°	1.5°	0.8°
α/ϕ_2 (WA)	4°	2°	0.6°	0.3°
$\lvert V_{ub}\rvert$ (Exclusive)	4.5%	2%	1%	< 1%
$S_{CP}(B \to \eta' K^0_S)$	0.08	0.03	0.015	0.007
$A_{CP}(B \to \pi^0 K^0_S)$	0.15	0.07	0.025	0.018
$S_{CP}(B \to K^{*0}\gamma)$	0.32	0.11	0.035	0.015
$R(B \to K^* \ell^+ \ell^-)^\dagger$	0.26	0.09	0.03	0.01
$R(B \to D^* \tau\nu)$	0.018	0.009	0.0045	<0.003
$R(B \to D \tau\nu)$	0.034	0.016	0.008	<0.003
$\mathcal{B}(B \to \tau\nu)$	24%	9%	4%	2%
$B(B \to K^* \nu\bar{\nu})$	–	25%	9%	4%
$\mathcal{B}(\tau \to \mu\gamma)$ UL	42×10^{-9}	22×10^{-9}	6.9×10^{-9}	3.1×10^{-9}
$\mathcal{B}(\tau \to \mu\mu\mu)$ UL	21×10^{-9}	3.6×10^{-9}	0.36×10^{-9}	0.073×10^{-9}

Table 2: Projected precision (total uncertainties, or 90% CL upper limits) of selected flavour physics measurements at Belle II.(The † symbol denotes the measurement in the momentum transfer squared bin $1 < q^2 < 6$ GeV$/c^2$.)

Snowmass White Paper: Belle II physics reach and plans for the next decade and beyond

https://arxiv.org/abs/2207.06307

Snowmass Whitepaper: The Belle II Detector Upgrade Program

https://arxiv.org/abs/2203.11349

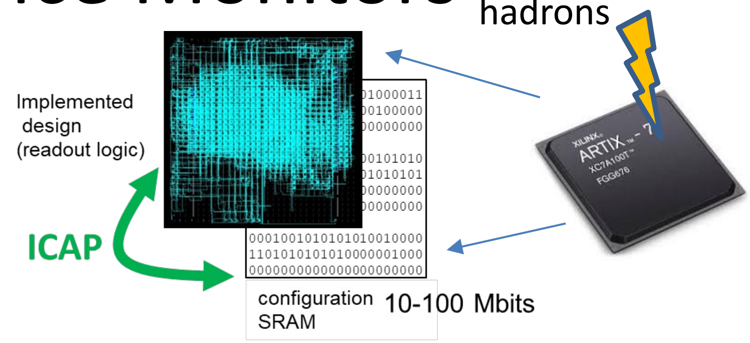
Grazie !

Backup

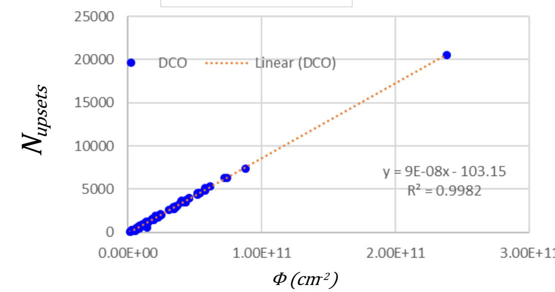
FPGA-Based Hadron Fluence Monitors

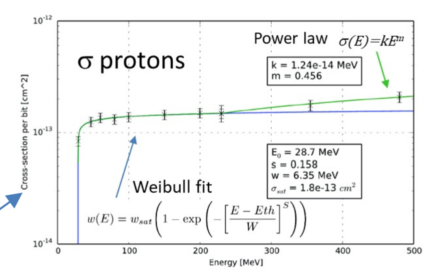
- Interest of Belle II background community for single-event upset monitoring in on-detector FPGAs [1] and neutron-related background in general
- Novel FPGA-based sensors developed in PHI experiment (CSNV)
  - Single device: configuration SRAM of FPGA as sensitive element and programmable logic as readout
  - Compact, reprogrammable, low-power, digital output
  - Sensor and interface boards developed and tested
  - Configuration SRAM Cross section characterization in progress, i.e. cross-section for protons/neutrons vs energy (JSI TRIGA and TIFPA beam tests)

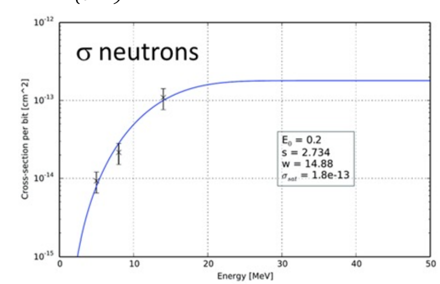
[1][Talk at biweekly beam background meeting]



$$\Phi = \frac{N_{upsets}}{\sigma\, N_{bits}}$$



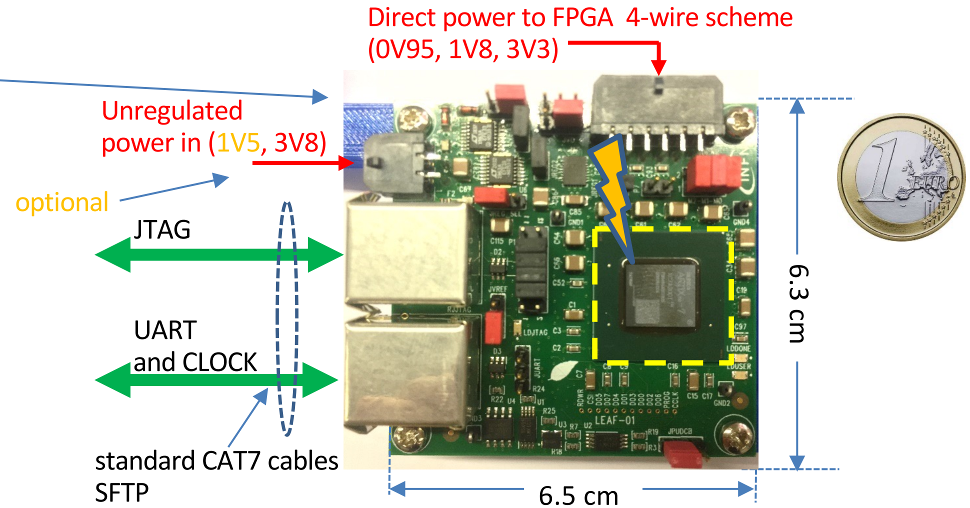


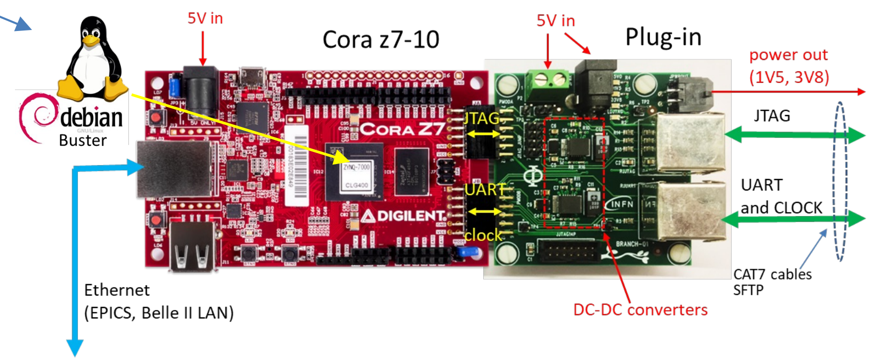


Typical cross section from Cypress SRAM-based sensors [1] doi: 10.1109/TNS.2014.2365042

Sensor and Interface Board

- Compact sensor board (6.3cm x 6.5cm)
  - Only COTS components, radiation tolerance studies in [1,2]
  - Dual power input mode: direct or via-regulators
  - Low power consumption (~0.7 W)
- Sensor: Xilinx Artix-7 200T FPGA
  - 28nm CMOS
  - Expected proton(>20MeV)-SEU σ = $9.4 \cdot 10^{-15}$ $cm^2 b^{-1}$, sensitivity = $1.4 \cdot 10^6$ pp/cm^2
- Interface board for sensor readout via Ethernet
  - Digilent Cora z7-10 based on Zynq-7000 (FPGA+ARM uP) + custom plug-in board
  - Automatic Cable Delay Compensation for fast JTAG over distances up to 40 m



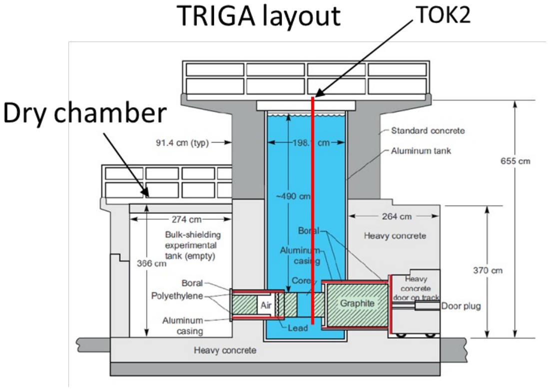


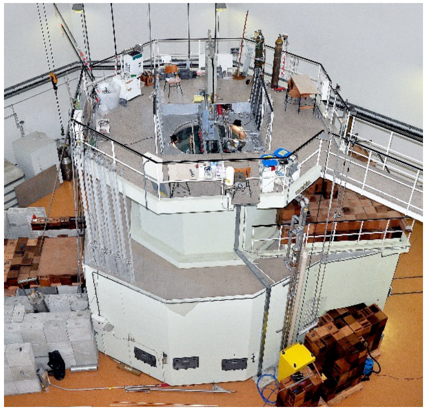
[1] T. Higuchi et al., 2012, doi: 10.1088/1748-0221/7/02/C02022
[2] Y. Yu Nakazawa et al., 2020, doi: 10.1016/j.nima.2019.163247

Irradiation Testing

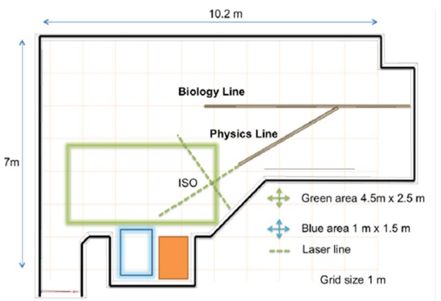
- Irradiation tests at the TRIGA nuclear reactor of Jožef Stefan Institute (Ljubljana, Slovenia)
  - Broad neutron spectrum (thermal, epithermal, fast)
  - 2 sensors tested
  - Flux ~ $10^8 – 10^9$ n/(cm^2·s)
  - thermal neutron $\sigma N_{bits} = 7.0 \cdot 10^{-8}$ cm^2 and neutron tolerance > 10^{12} n_{eq}/cm^2
  - Readout logic $\sigma_{fail} = 5.1 \cdot 10^{-12}$ cm^2 (thermal n)
- σ(Energy, V_{DD}) characterization at Trento Institute for Fundamental Physics and Applications (Trento, Italy)
  - monoenergetic protons, tunable energy in 70-228 MeV range
  - 6 sensors tested
  - Flux ~ 10^9 p/(cm^2·s)
  - Data analysis in progress

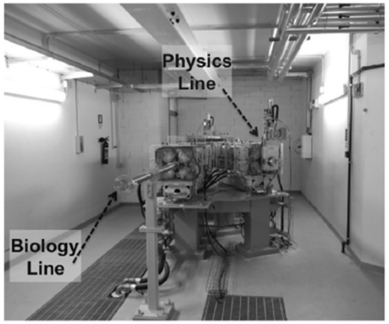
TRIGA layout





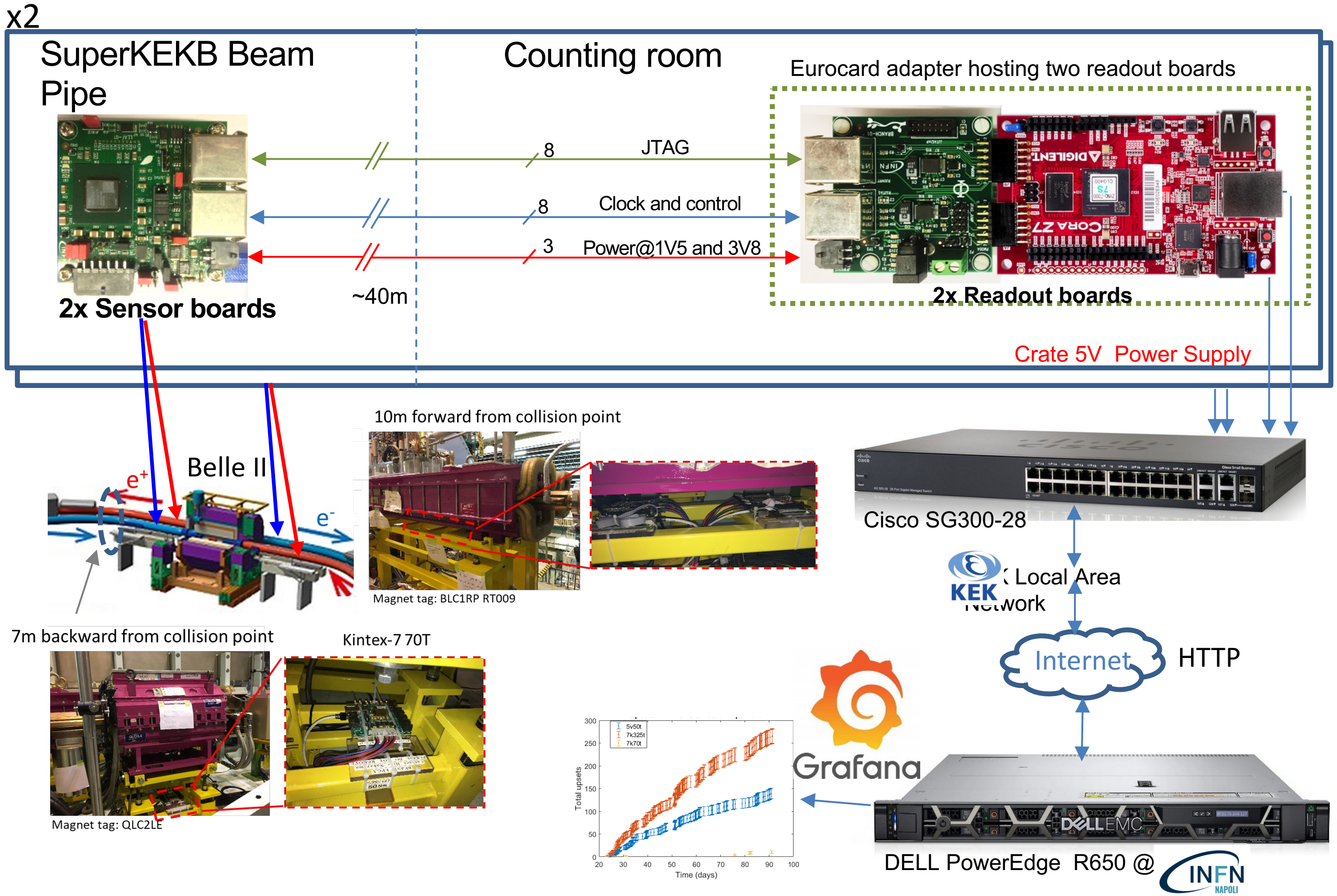
TIFPA Irradiation Room



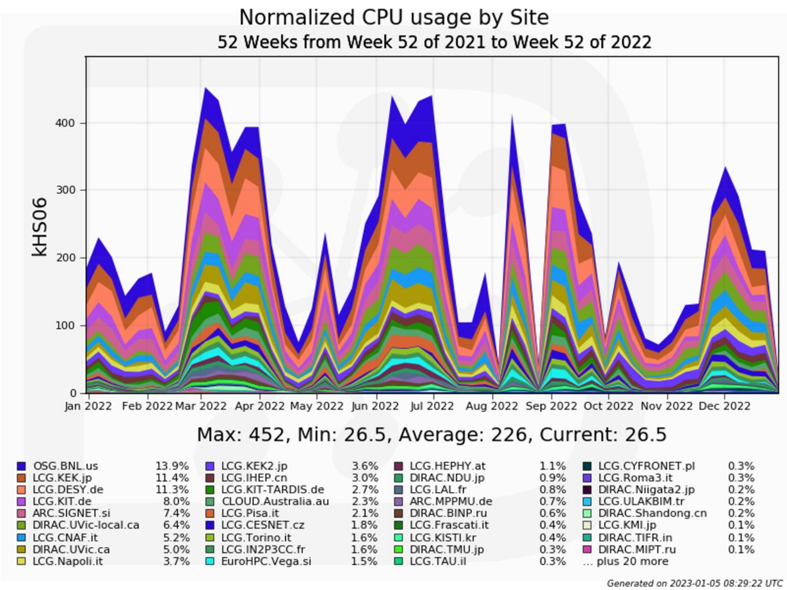


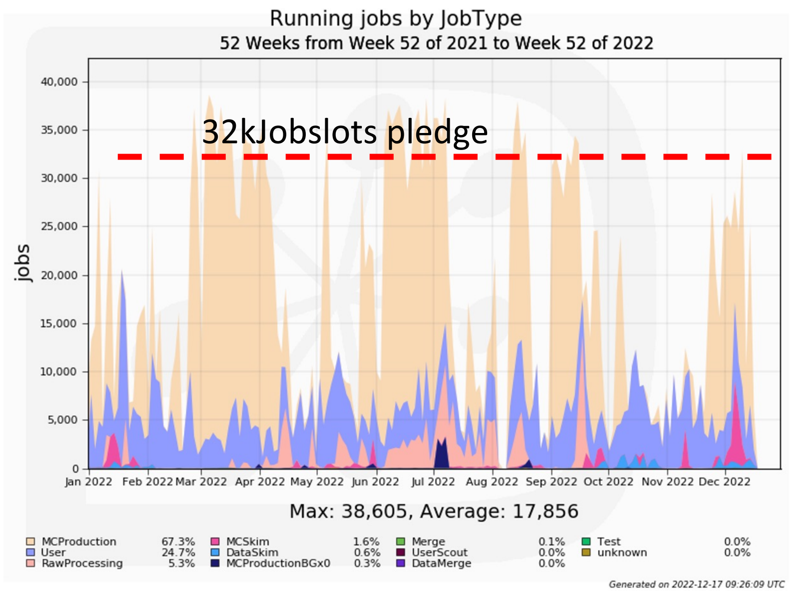
FPGA-based Neutron Fluence Monitors at Belle II

- 4 sensors + 4 readout boards: 2 at forward (e+/e-) plus 2 at backward (e+/e-)
- Installation: 2 travels to KEK for two people in 2023 (before end of LS1)
- EPICS support for integration with other Belle II monitors
- Back-end server at INFN NA for data collection and web publication (Grafana)
- Easy access to data for the whole Collaboration
- System modularity makes it possible to scale number of sensors over time



Attività di computing 2022

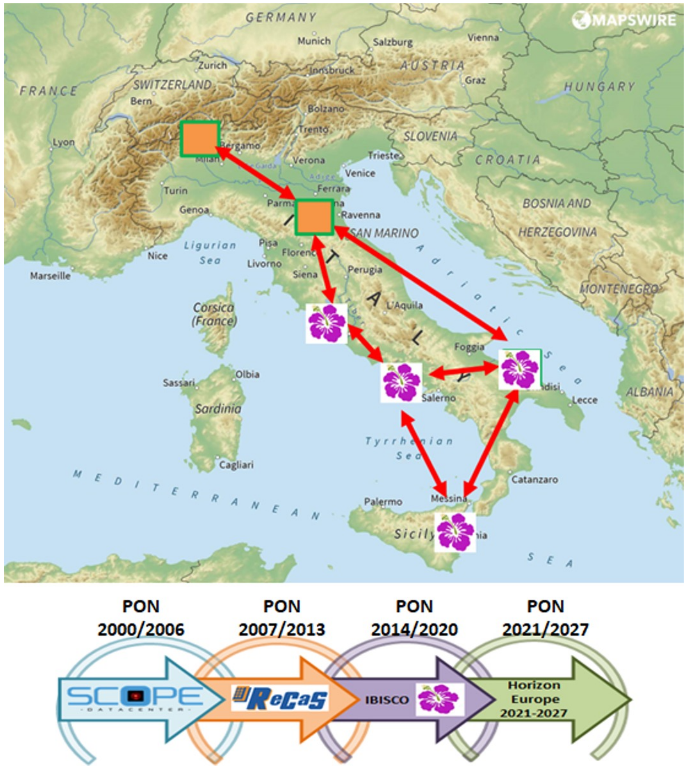




Milestone Italiana per il 2022: fornire il 12% de MC. Italian Share fornito: 13.3%

- Attività user analysis aumentata rispetto al 2021
- Picchi di ~40 k jobs running
- **Il sito di Napoli è il primo sito della collaborazione per potenza di calcolo fornita dopo i RAW Data Center**

Progetto IBISCO e PNRR



Nuovo hardware di Belle II fornito con il progetto IBISCO.

I.Bi.S.Co. (Infrastructure for Big Data and Scientific Computing)

- Napoli (INFN Unit + University Federico II)
- 10 PB of disk space - **1PB per Belle II (590TB Pledged)**
- 110 Server per HTC - **16 server renewal pledged Belle II**
- Cloud Cluster (that will be part of INFN Cloud)
- HPC Resources with GPU

Datacenter in ulteriore espansione con il PNRR.

(Guido Russo, Silvio Pardi per Belle II. Grazie Alessandra Doria, Bernardino Spisso, Michele Delli Veneri e tutto il gruppo di IBISCO per il supporto)

INFN-Napoli Leadership sulle nuove tecnologie

Responsabilità:

Silvio Pardi Coordinatore Italiano del Computing e Infrastructure Coordinator per l'esperimento

Attività in corso:

- Transizione alla token-based-authentication in sostituzione dei certificati x509
  - Prototipo del sistema di autenticazione presso il CNAF
  - Testbed gestito da Napoli
- Transizione al protocollo WebDAV al posto degli storici protocolli GridFTP/SRM
  - Sistema di monitoraggio e processo di transizione gestito da Napoli
- Implementazione dei Job Multicore
  - Configurazioni gestite da Napoli

$D^* \to D\gamma$ sample

This channel is optimal to study the low energy photon resolution. We can extract the photon resolution from $\Delta M = M_{D^*} - M_D$ because the tracking resolution component is negligible: $\sigma_{\mathrm{tr}}(\Delta M) \approx 0.5$ MeV.
The reconstructed decays are:

$D^{0*} \to D^0\gamma$

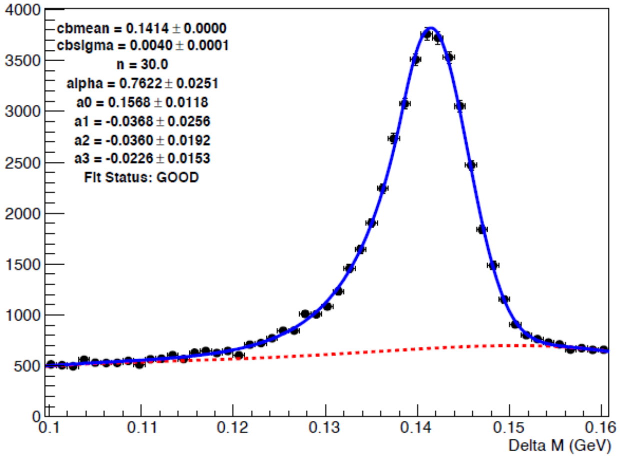
$D^0 \to K\pi(4\%)$ $D^0 \to K_s\pi\pi(2{,}8\%)$ $D^0 \to K\pi\pi\pi(8\%)$

$D_s^* \to D_s\gamma$

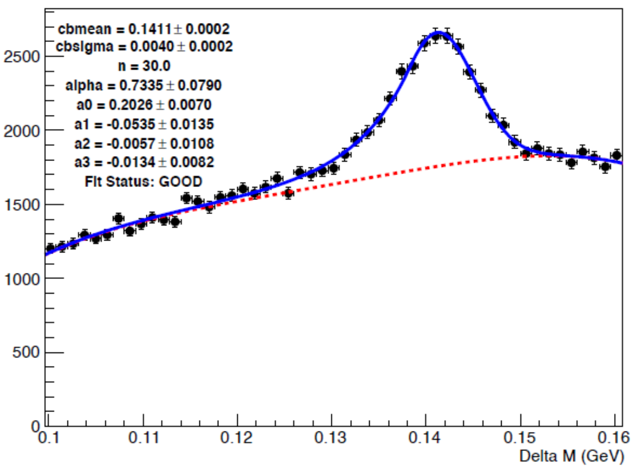
$D_s \to K_S\pi(1{,}5\%)$ $D_s \to \overline{K}^* K(2{,}6\%)$ $D_s \to \phi\pi(2{,}2\%)$

Finally we have performed a fit over ΔM: Crystal ball for the signal and a 3th order Chebychev polynomial for the combinatorial background.

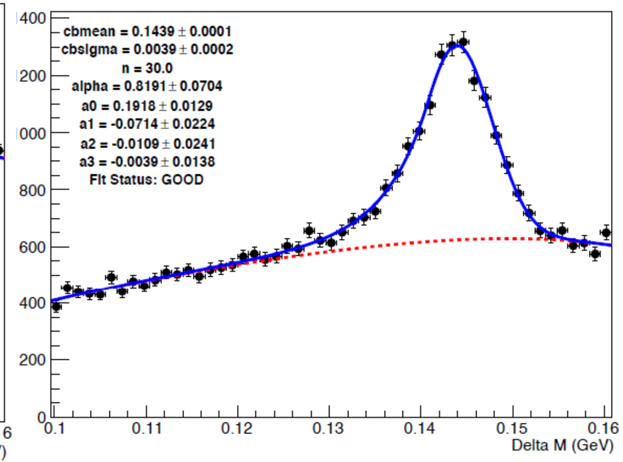
ΔM distribution: 400 – 600 MeV



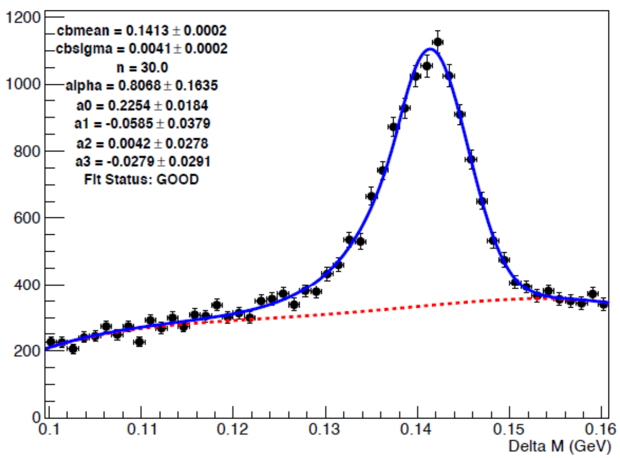
$D^0 \rightarrow K\pi$



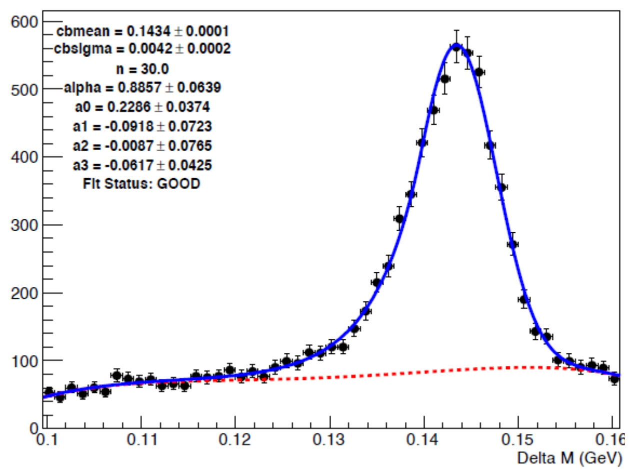
$D^0 \rightarrow K_S\pi\pi$



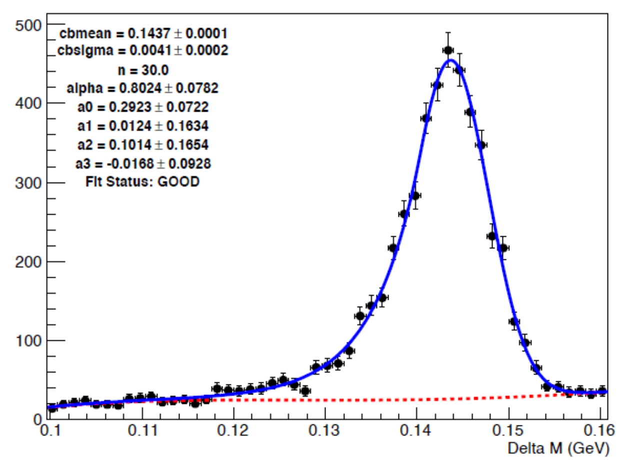
$D_s \rightarrow \overline{K}^* K$



$D^0 \rightarrow K\pi\pi\pi$



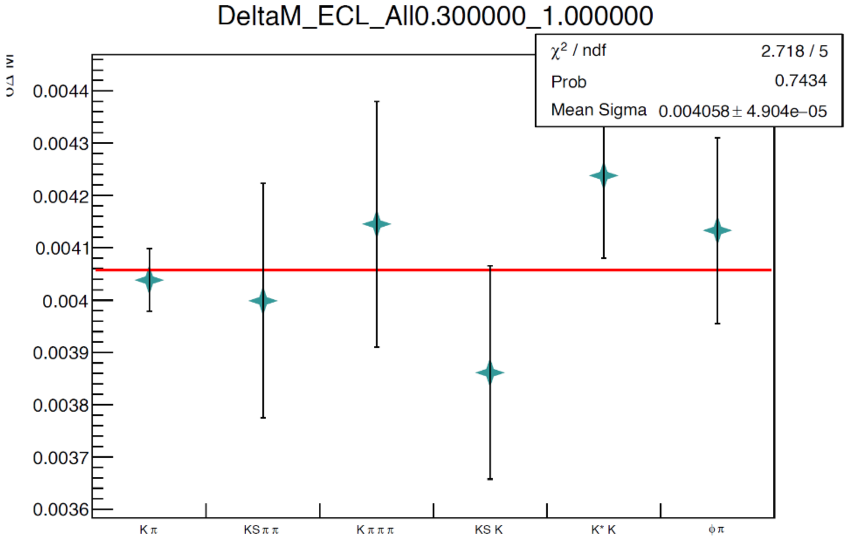
$D_s \rightarrow K_S K$



$D_s \rightarrow \phi\pi$

Mixing all the channels

To combine the six decay channels we computed the weighted average of the crystal ball σ



γ Energy (MeV)	σ_{Data}(MeV)	σ_{MCri}(MeV)	σ_{MCrd}(MeV)	Ratio MCri	Ratio MCrd
$100-200$	(4.98 ± 0.76)	(5.12 ± 0.17)	(4.91 ± 0.19)	(0.97 ± 0.15)	(1.01 ± 0.16)
$200-400$	(4.74 ± 0.13)	(4.50 ± 0.06)	(4.50 ± 0.05)	(1.05 ± 0.03)	(1.05 ± 0.03)
$400-600$	(4.16 ± 0.06)	(3.77 ± 0.02)	(3.88 ± 0.03)	(1.10 ± 0.02)	(1.07 ± 0.02)
$600-1000$	(3.69 ± 0.17)	(3.27 ± 0.05)	(3.25 ± 0.05)	(1.13 ± 0.06)	(1.14 ± 0.06)
$300-1000$	(4.09 ± 0.05)	(3.85 ± 0.02)	(3.80 ± 0.02)	(1.06 ± 0.01)	(1.08 ± 0.01)

Strategy

- MC/Data comparison of π^0 detection efficiency via the decay chain

$$e^+e^- \rightarrow \omega(782)\gamma_{ISR} \rightarrow \pi^+\pi^-\pi^0\gamma_{ISR}$$

- Efficiency definition
  - N_ω: number of events with meson ω production selected using beam, π^+, π^- and γ_{ISR} information, no requests on π^0 detection (control sample)
  - N_{π^0}: number of control sample events with $\pi^0 \rightarrow \gamma\gamma$ detected with standard cuts
  - $\varepsilon_{\pi^0 MC} = \left({}^{N_{\pi^0}}/_{N_\omega}\right)_{MC}$ and $\varepsilon_{\pi^0 Data} = \left({}^{N_{\pi^0}}/_{N_\omega}\right)_{Data}$

- MC sample (1ab^{-1} per sample)
  - $e^+e^- \rightarrow \pi^+\pi^-\pi^0\gamma_{ISR}$
  - $e^+e^- \rightarrow \pi^+\pi^-\gamma_{ISR}$
  - $e^+e^- \rightarrow \pi^+\pi^-\pi^0\pi^0\gamma_{ISR}$
  - $e^+e^- \rightarrow \mu^+\mu^-\gamma_{ISR}$
  - $e^+e^- \rightarrow K^+K^-\gamma_{ISR}$

  Main backgrounds ($\pi^+\pi^-\gamma_{ISR}$, $\pi^+\pi^-\pi^0\pi^0\gamma_{ISR}$)

  Negligible contributions (< 1.‰) ($\mu^+\mu^-\gamma_{ISR}$, $K^+K^-\gamma_{ISR}$)

- Data sample (326.6 fb^{-1})

Control sample selection

Charged particle

- From stdPi list
- thetaInCDCAcceptance > 0 and thetaInECLAcceptance > 0
- dr < 2cm and |dz| < 4cm
- nCDCHits > 20
- pionID > 0.9, pt > 0.2 GeV

γ_{ISR}

- From stdPhotons list
- thetaInECLAcceptance > 0
- E_{CMS} > 4.5 GeV

Event selected if $N_{charged +}$ >=1, $N_{charged -}$ >=1 and N_{gamma} >= 1

For each triplet (π^+, π^- and γ_{ISR}) kinematic fits with KFit tool.

- **In order to reject the main background $e^+e^- \to \pi^+\pi^-\gamma_{ISR}$:**

  4CFit: mother particle's 4-momentum constrained to the beam 4-momentum → **If $\chi^2_{4C} < 300$ triplet rejected**

- **1CFit: π^0 fitted requiring $e^+e^- \to \pi^+\pi^-\gamma_{ISR}p_{miss}$, with $p^2_{miss} = m^2_{\pi^0}$ and beam energy as constraints**

Just the triplet with the highest $P_{\chi^2_{1C}}$ (> 0.4) selected in the event

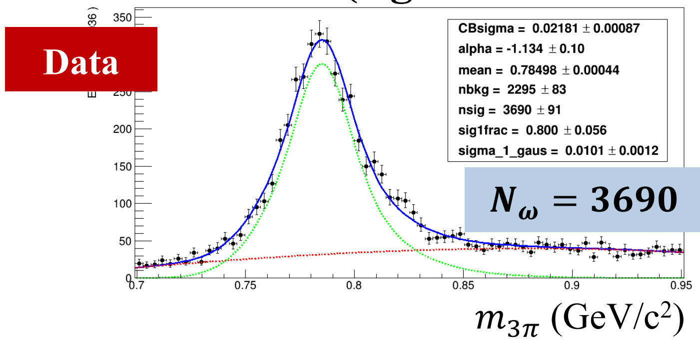
Efficiency definition

- Squared invariant mass of the 3 pion system

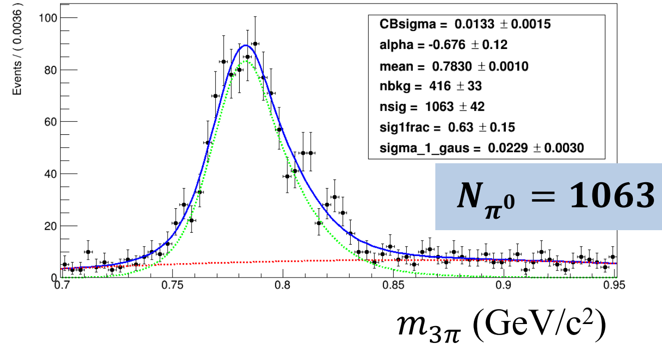
$$m_{3\pi}^2 = \left(P_{\pi^+} + P_{\pi^-} + P_{\pi^0}\right)^{\alpha}\left(P_{\pi^+} + P_{\pi^-} + P_{\pi^0}\right)_{\alpha}$$

P_{π^+} and P_{π^-} from momentum measurement + pion hypothesis, P_{π^0} from kin fit estimate

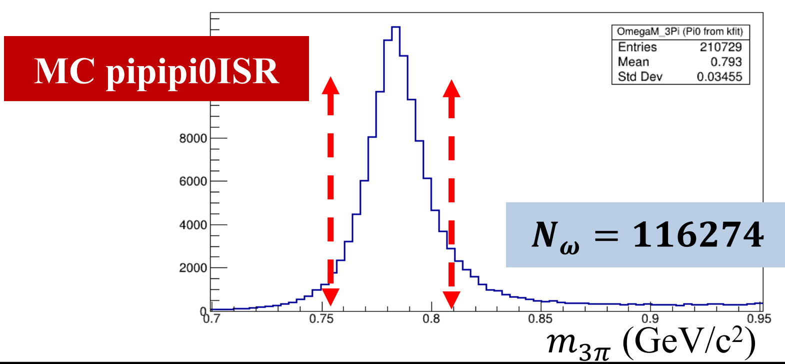
- Two different efficiencies :
  - Fit to $m_{3\pi}$ distribution to evaluate N_ω before and after π^0 selection - both for data and full MC (signal + main backgrounds)



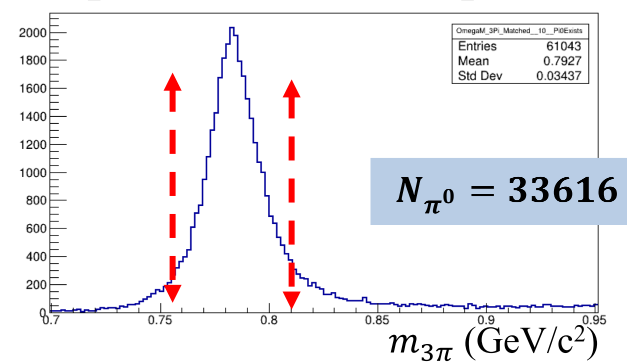
π^0 selection



  - Count events in $m_{3\pi}$ distribution for $|m_{3\pi} - m_\omega| < 3\sigma$ to evaluate N_ω before and after π^0 selection - for $e^+e^- \to \pi^+\pi^-\pi^0\gamma_{ISR}$ MC sample (to validate fit procedure)



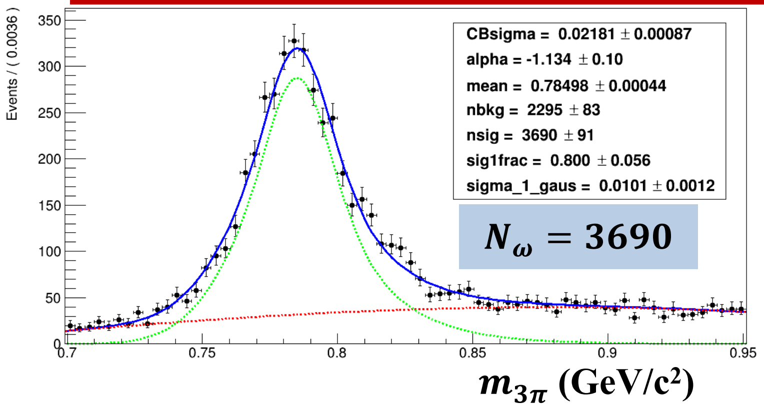
π^0 selection



Efficiency uncertainty

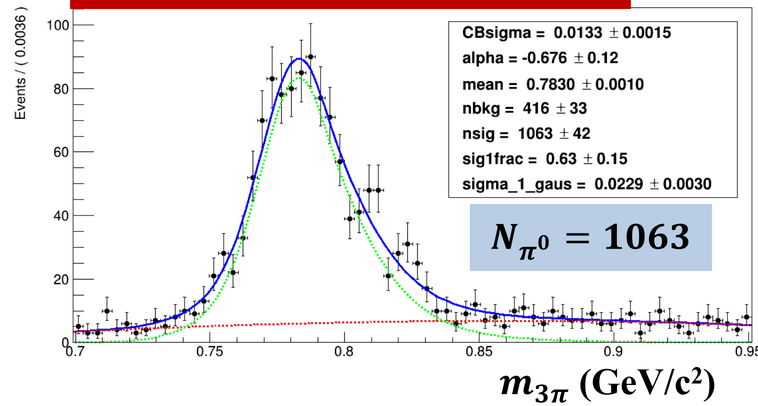
- **Counting technique (MCsignal): binomial approximation ($\sqrt{\hat{\varepsilon}_{\pi^0}(1-\hat{\varepsilon}_{\pi^0})/N_\omega}$)**
- **Fit technique (data and full MC): toy-MC to evaluate the $\hat{\varepsilon}_{\pi^0}$ uncertainty**

Data: $\hat{H}_\omega$ histogram with N_{Den} entries

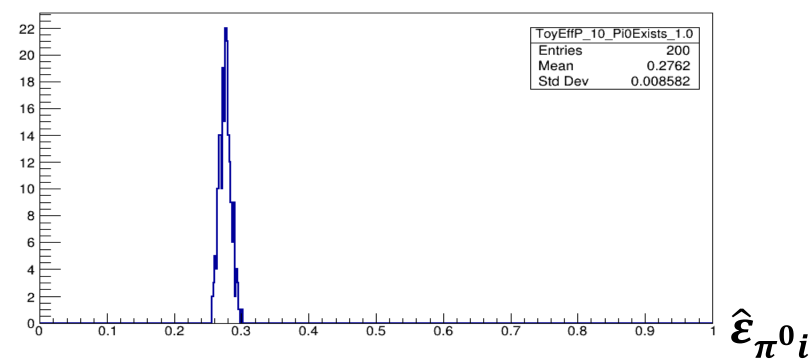


π^0 selection

Data Pi0_eff10: $\hat{H}_{\pi^0}$ histogram



- Generate Poisson(N_{Den}) events according to the $\hat{H}_\omega$ histogram → fit to compute $\hat{N}_{\omega 1}$
- Generate N_{Num} events according to the $\hat{H}_{\pi^0}$ histogram; N_{Num} defined to keep the same average $\hat{\varepsilon}_{\pi^0}$ signal efficiency and signal to noise ratio observed in data → fit to compute $\hat{N}_{\pi^0 1}$
- Evaluate $\hat{\varepsilon}_{\pi^0 1} = \hat{N}_{\pi^0 1}/\hat{N}_{\omega 1}$
- Repeat the experiment → $\hat{\varepsilon}_{\pi^0 i}$ distribution



π^0 detection efficiency

- ε_{π^0} can be evaluated in bin of momentum, θ and φ of the fitted π^0