B-Physics with Belle and Preparations for Belle II at SuperKEKB

C. Kiesling,
for the MPI Belle Group

- Physics Motivation
- Analyses of the Full Belle Data Sample at MPI
- Belle II and the PXD Project
    - e.g. Beam Test of First Thin Sensors
    - Mechanics and CO2 Cooling
- Schedule and Risks
- Conclusions

The Belle (II) Group at MPI

Director: Allen Caldwell

Staff

Laci Andricek, Christian Kiesling, Hans-Günther Moser,
Rainer Richter, Vladimir Shekelyan, Frank Simon

W2 Minerva: Jelena Ninkovic

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Kolja Prothmann, Andreas Ritter, Martin Ritter, Pit Vanhoefer

Diploma Students

Veronika Chobanova

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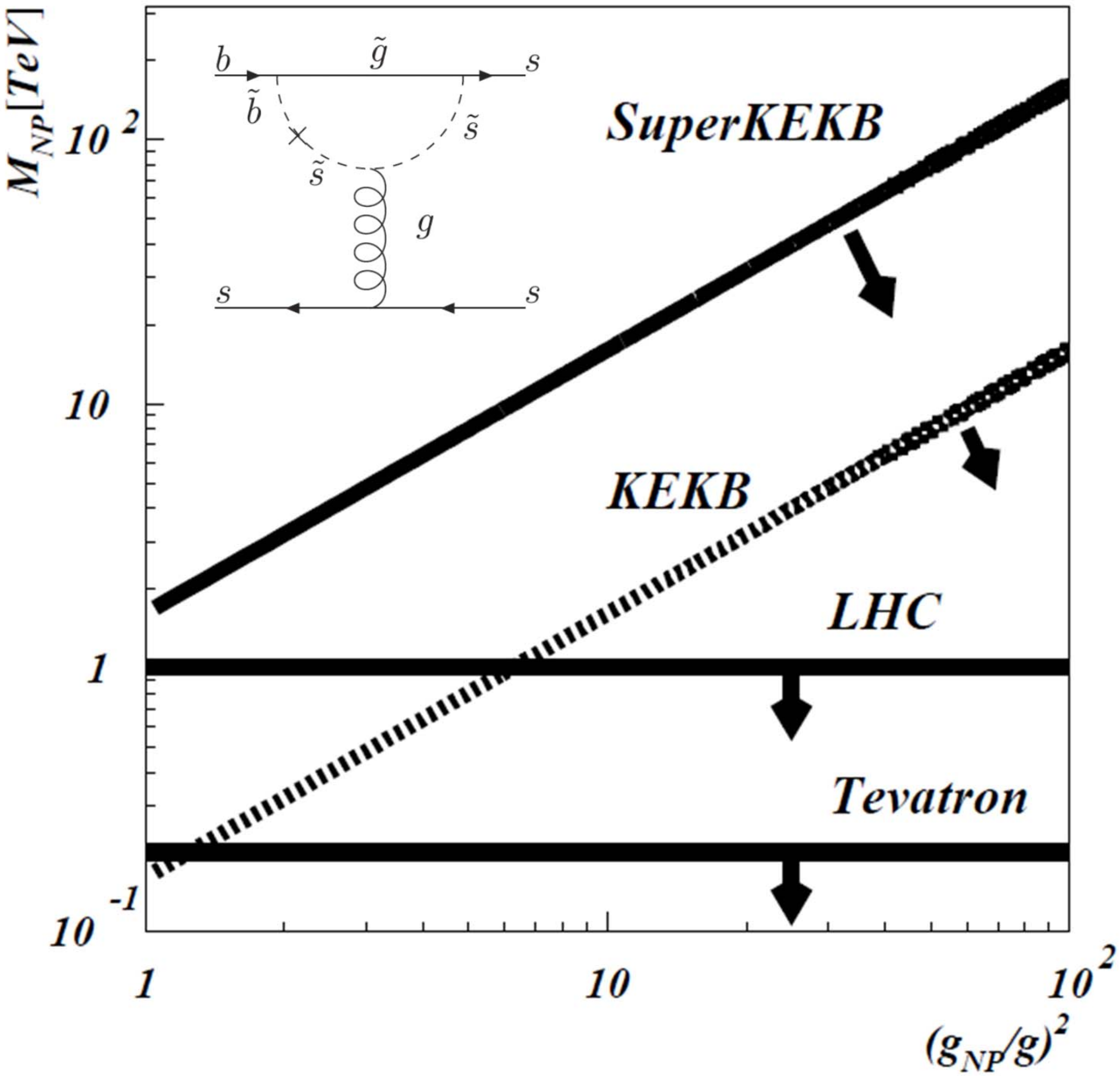
Mandi Wenninger, Holger Wetteskind

Technology@HLL

Anastasia Plis, Martina Schnecke, Gerhard Schaller (MPE),
Florian Schopper (MPE), Klaus Heinzinger (PNS), Rouven Eckardt (PNS)

Sensitivity to New Physics



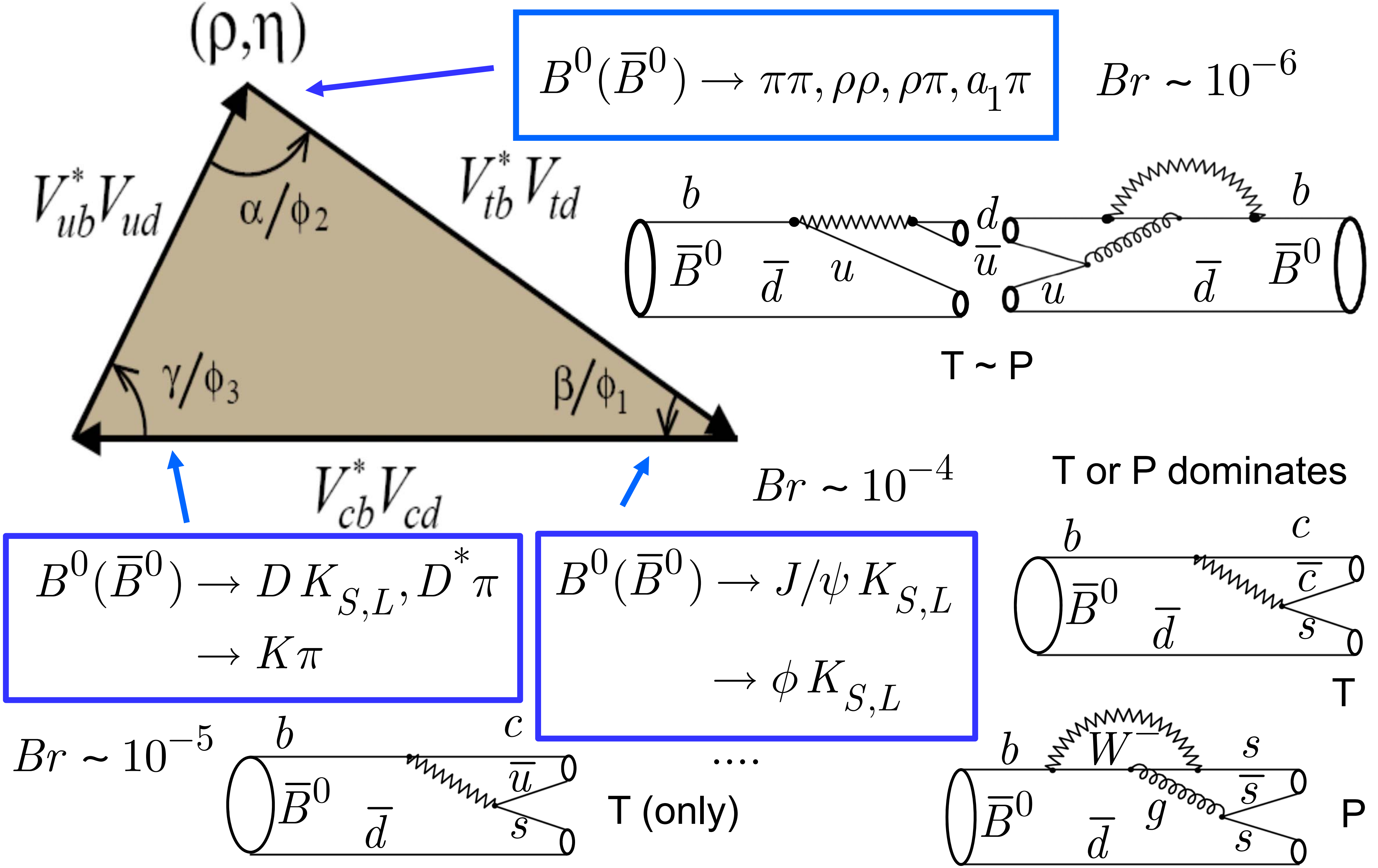
complementary to the LHC:

Searching for deviations from the SM with Super Flavor Factories

indirect discovery of New Physics in quantum loops via high precision measurements:

CP Violation BSM
rare decays

Measuring the Angles (Φ_1,Φ_2,Φ_3)



$B^0(\bar{B}^0) \to \pi\pi, \rho\rho, \rho\pi, a_1\pi$

$Br \sim 10^{-6}$

T ~ P

$Br \sim 10^{-4}$

T or P dominates

$B^0(\bar{B}^0) \to D\,K_{S,L}, D^*\pi$

$\to K\pi$

$B^0(\bar{B}^0) \to J/\psi\,K_{S,L}$

$\to \phi\,K_{S,L}$

T

$Br \sim 10^{-5}$

....

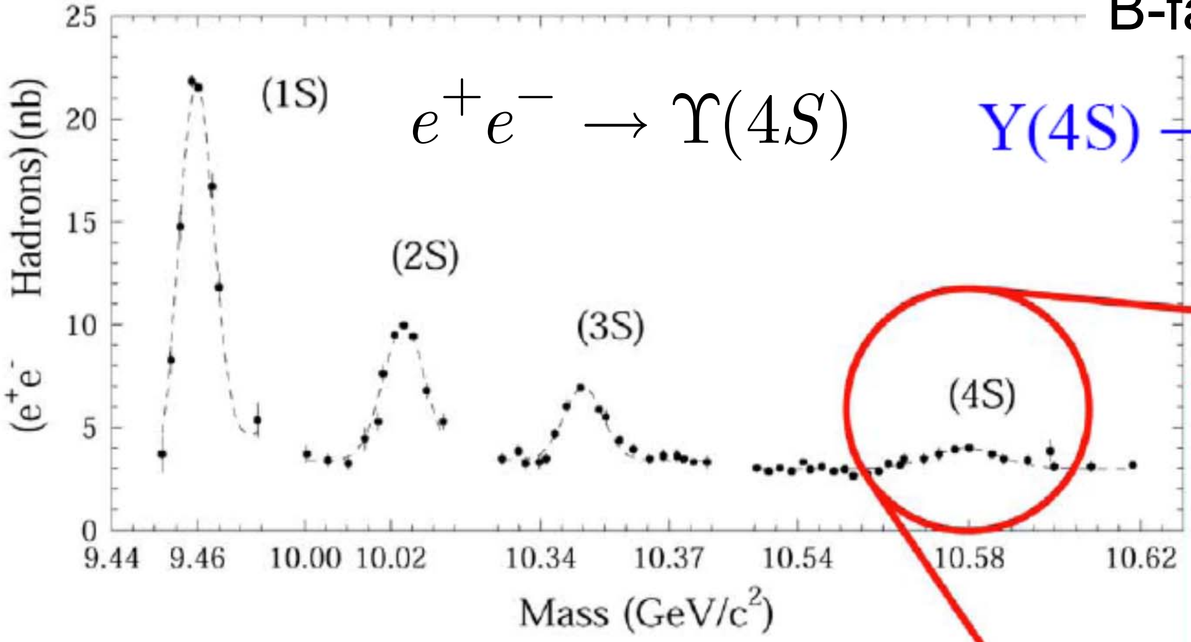
T (only)

P

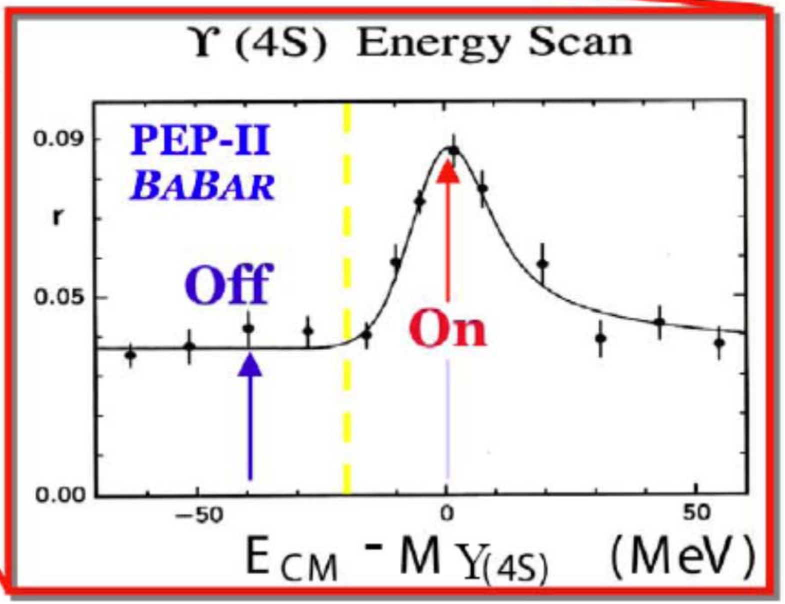
Where do we Measure?

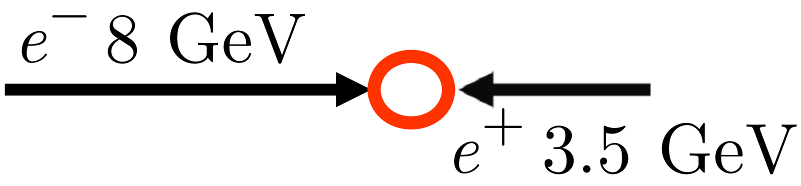
B-factories at KEK and SLAC

$Y(4S)$ -> $B^0 \bar{B}^0$ (50%), $B^+ \bar{B}^-$ (50%)



$$e^+e^- \to \Upsilon(4S)$$





e^- 8 GeV

e^+ 3.5 GeV

B-mesons are produced exclusively !

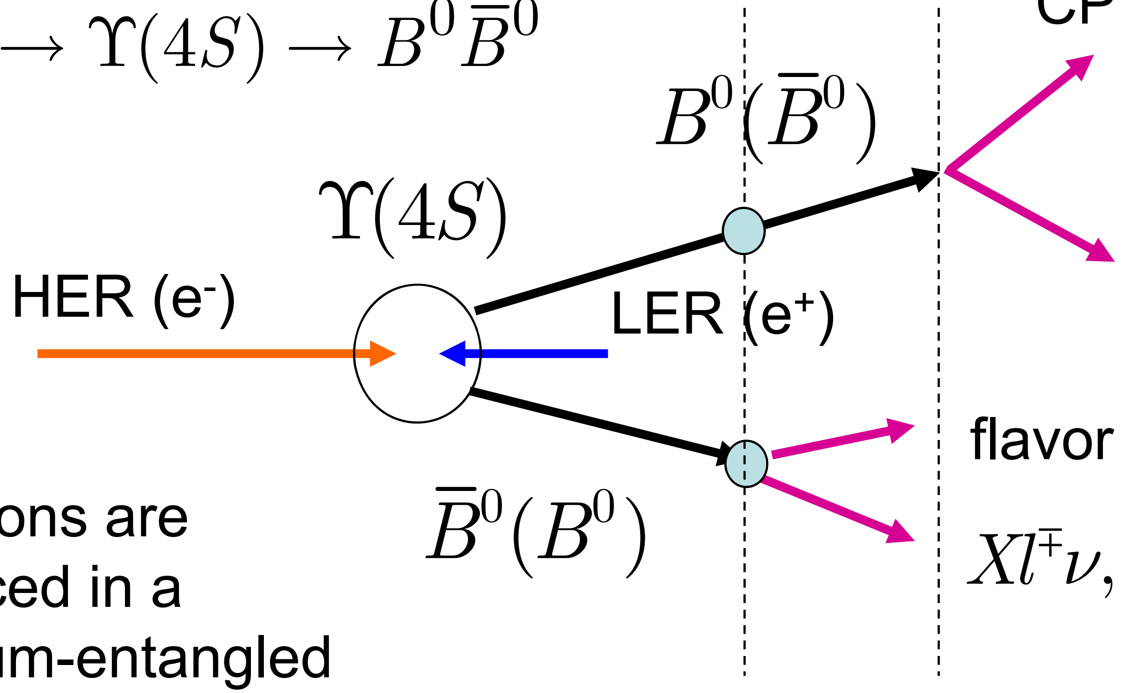
Beam energies are asymmetric:
both B‘s have the same Lorentz boost,
fly parallel in the lab system

large background („continuum“)
below the resonance peak:
S/B ~ 1/4

The ~~CP~~ Observables: What do we measure?

B-Mesons: $\left|B^0\right\rangle = \left|\bar{b}d\right\rangle \quad \left|B^+\right\rangle = \left|\bar{b}u\right\rangle$

$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B^0\bar{B}^0$



some state $f(\bar{f})$ or CP eigenstate, e.g.

$J/\psi K_S$ the „Golden“ channel

$CP = -1$

flavor eigenstate

$Xl^{\mp}\nu, D^{*\pm}X$ „flavor tagging“

B mesons are produced in a quantum-entangled state !

$$\Delta z = \beta\gamma c\Delta t$$

Asymmetric beam energies: translate decay time to decay length vertex detector essential (PXD for Belle II)

Example: Mixing-Induced CP Violation

$$A = \left\langle \psi_{CP} \mid B^0 \right\rangle; \quad \bar{A} = \left\langle \psi_{CP} \mid \bar{B}^0 \right\rangle$$

ψ_{CP} : CP eigenstate

$$\begin{tikzcd}
B^0 \arrow[rr, "A"] \arrow[dr, dashed, "\frac{q}{p} = e^{-i2\phi_1}"'] & & \psi_{CP} & \neq & \bar{B}^0 \arrow[rr, "\bar{A}"] \arrow[dr, dashed, "\frac{p}{q}"'] & & \psi_{CP} \\
& \bar{B}^0 \arrow[ur, dashed, "\bar{A}"'] & & & & B^0 \arrow[ur, dashed, "A"'] &
\end{tikzcd}$$

$$\lambda_\psi = \frac{q}{p}\frac{\bar{A}}{A}$$

$$\mathcal{A}_{CP}(\psi, \Delta t) = \frac{\Gamma(B^0 \to \psi; \Delta t) - \Gamma(\bar{B}^0 \to \psi; \Delta t)}{\Gamma(B^0 \to \psi; \Delta t) + \Gamma(\bar{B}^0 \to \psi; \Delta t)}$$

$$= \underbrace{\frac{1 - \left|\lambda_\psi\right|^2}{1 + \left|\lambda_\psi\right|^2}}_{A_{CP}} \cos \Delta m \Delta t + \underbrace{\frac{2\,\mathrm{Im}(\lambda_\psi)}{1 + \left|\lambda_\psi\right|^2}}_{S_{CP}} \sin \Delta m \Delta t$$

„time-dependent CP asymmetry“

Ongoing and Planned Analyses @ MPI

Final analyses with full statistics (711 fb^{-1} , 772 M $B\overline{B}$ events)

Mode	Physics parameter(s) of interest
$B^0 \to D^{*+}D^{*-}K_S^0$ (signal MC started)	$\sin 2\phi_1, \cos 2\phi_1$
$B^0 \to \psi(2S)\pi^0$ (signal MC started)	$\sin 2\phi_1$
$B^0 \to K_S^0\pi^+\pi^-$	
$B^0 \to K^{*+}\pi^-, K^{*+}(1430)\pi^-$	$\mathcal{A}_{CP}$
$B^0 \to \rho^0K_S^0, f_0K_S^0, f_2K_S^0, f_XK_S^0, \chi_{c1}K_S^0$	ϕ_1
$B^0 \to K_S^0\pi^0$ (published)	$\mathcal{A}_{CP}, \sin 2\phi_1$
$B^0 \to \omega K_S^0$ (diploma thesis)	$\sin 2\phi_1$
$B^0 \to \pi^+\pi^-, K^+\pi^-, K^+K^-$ (Belle note)	$\mathcal{A}_{CP}, \sin 2\phi_2$
$B^0 \to \rho^0\rho^0$ (Belle note) , $\rho^+\rho^-$	$\sin 2\phi_2$
$B^0 \to a_1^{\pm}\pi^{\mp}$ (paper in preparation)	$\sin 2\phi_2$

tree / penguin consistency in Φ_1

„complete“ Φ_2 analysis

Members involved: V. Chobanova, J. Dalseno, C.K., S. Koblitz, E. Nedelkovska, K. Prothmann, M. Ritter, P. Vanhoefer

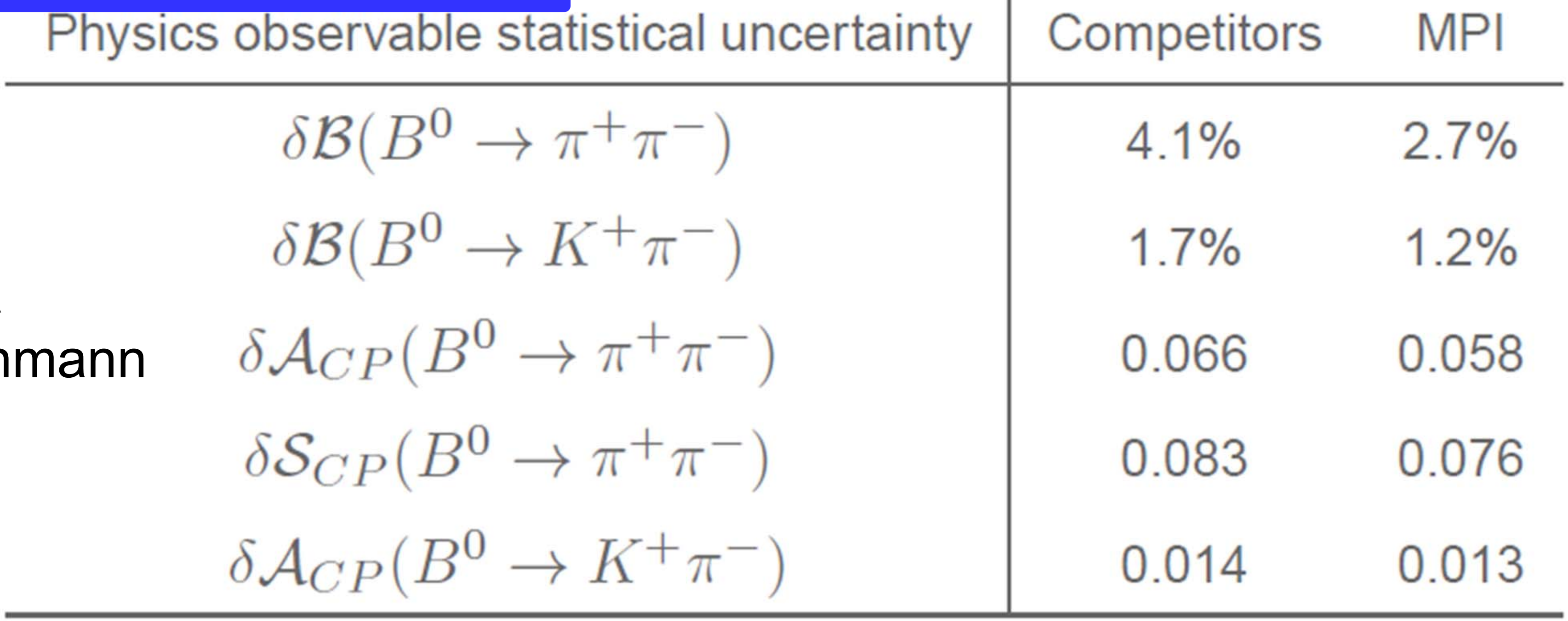
Analyses of Φ_2 (α)

- $b \to u\bar{u}d$ strongly suppressed by CKM matrix elements (T & P)

  → high background levels (other *B* decays, continuum)

- Standard Belle procedure: cuts on variables to optimize $S \,/\, \sqrt{S+B}$
- MPI analysis strategy: minimize # of cuts, instead use multi-variate fitting approach to get best signal sensitivity

$$\boxed{B^0 \to \pi^+\pi^-, K^+\pi^-}$$



Physics observable statistical uncertainty	Competitors	MPI
$\delta\mathcal{B}(B^0 \to \pi^+\pi^-)$	4.1%	2.7%
$\delta\mathcal{B}(B^0 \to K^+\pi^-)$	1.7%	1.2%
$\delta\mathcal{A}_{CP}(B^0 \to \pi^+\pi^-)$	0.066	0.058
$\delta\mathcal{S}_{CP}(B^0 \to \pi^+\pi^-)$	0.083	0.076
$\delta\mathcal{A}_{CP}(B^0 \to K^+\pi^-)$	0.014	0.013

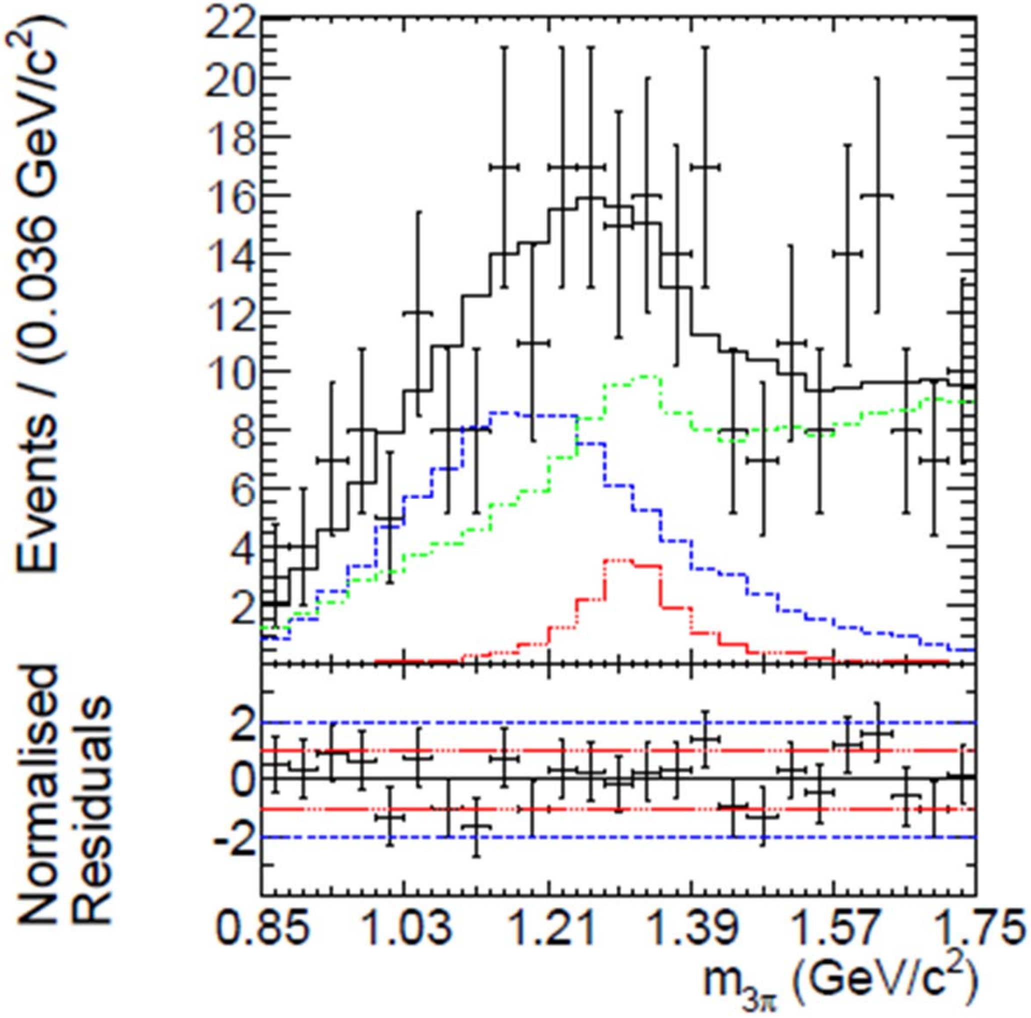
Kolja
Prothmann

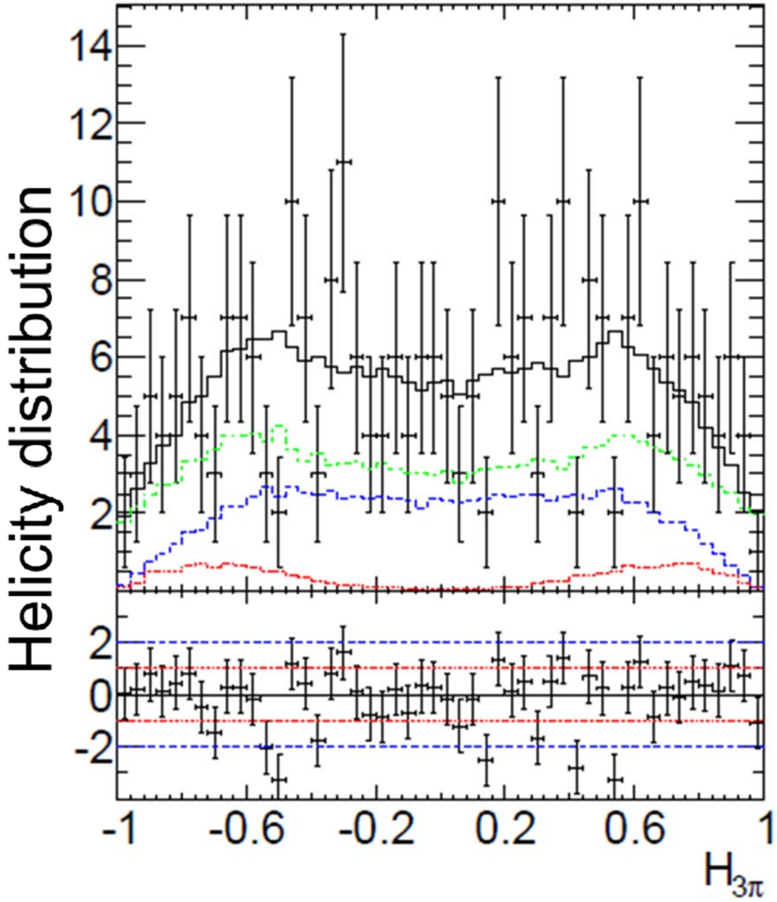
$B^0 \rightarrow a_1(1260)^+ \pi^-$

„large“ branching ratio, decay sensitive to tree / loop contributions
two unssuccessful attempts in Belle (problems with shape of a_1)

$a_1(1260)^+ \rightarrow \rho^0 \pi^-$

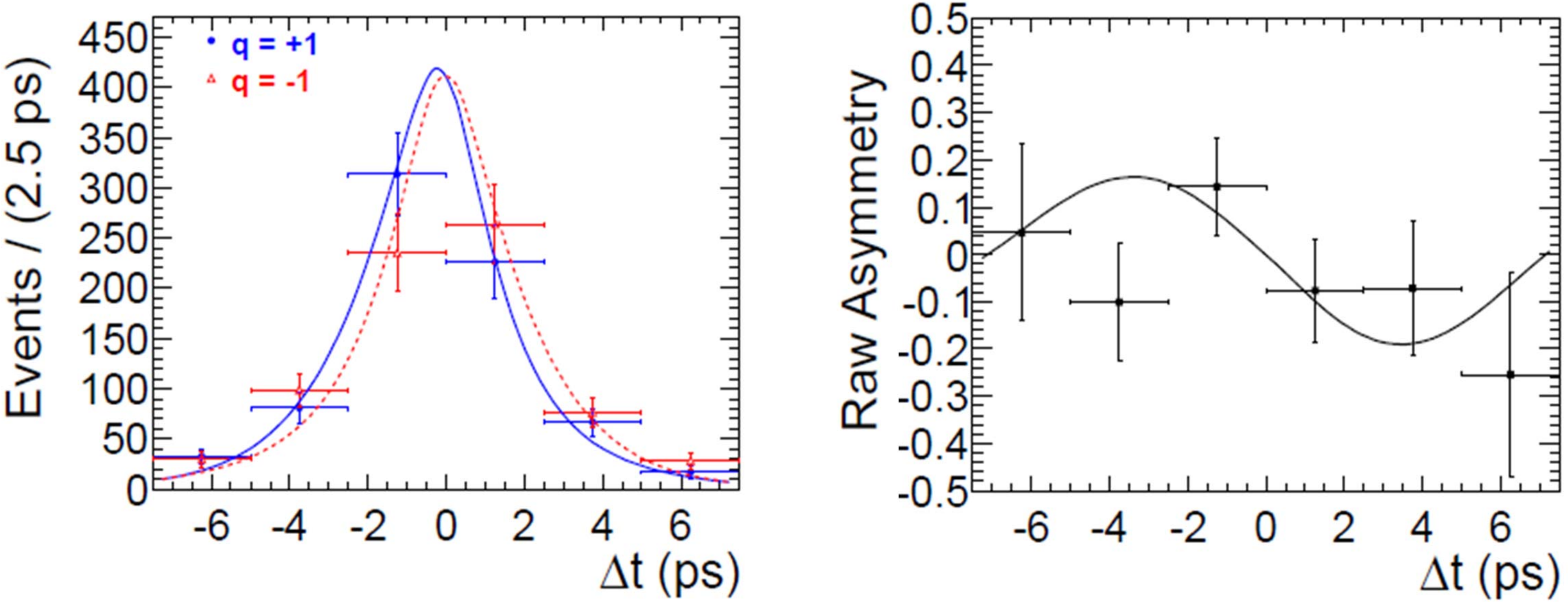
— line shape of a_1
— line shape of a_2
— total background





$B^0 \to a_1(1260)^+\pi^-$

Jeremy Dalseno



First evidence of CP violation in $B^0 \to a_1^\pm \pi^\mp$

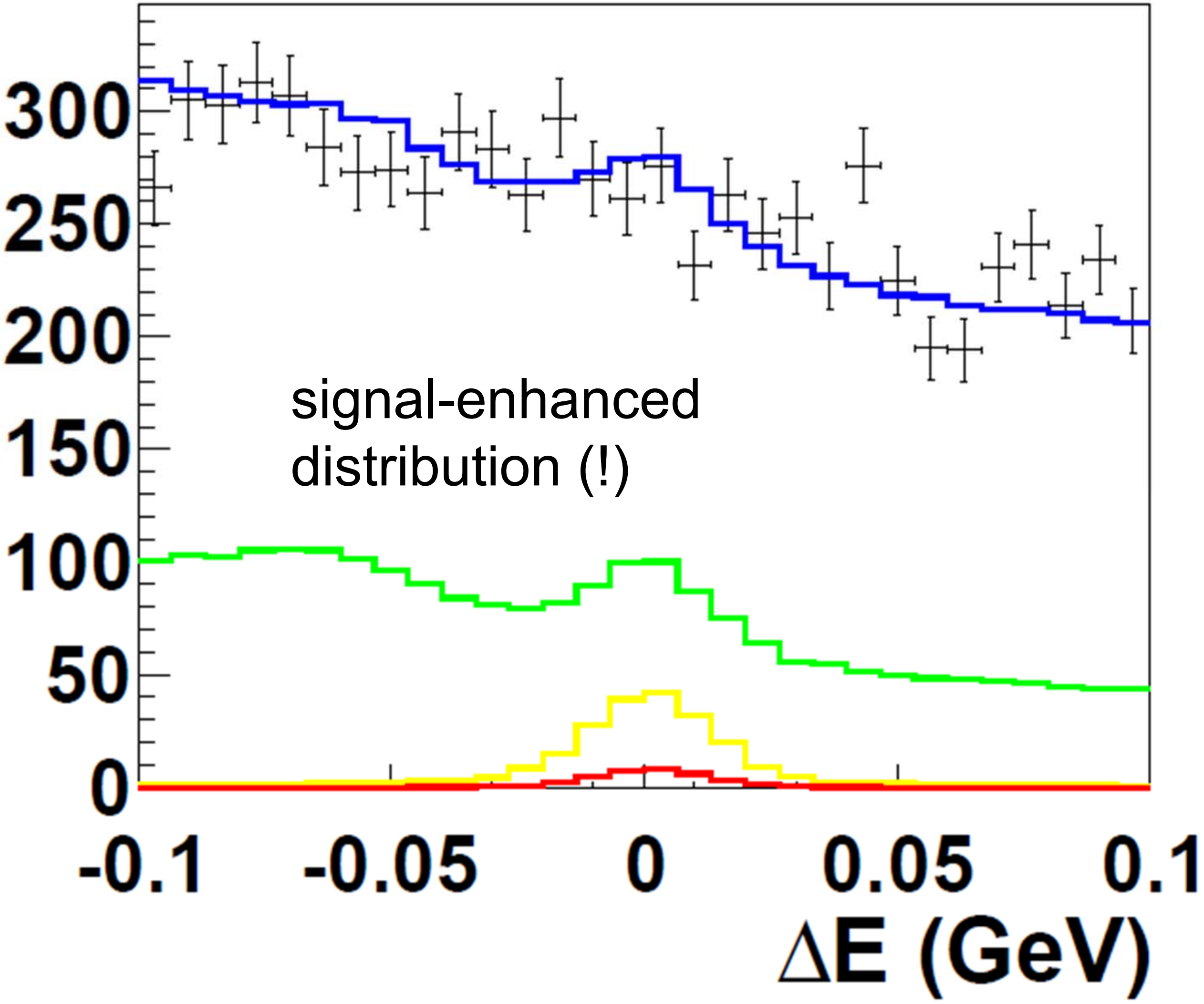
$$\mathcal{S}_{CP} = -0.51 \pm 0.14 \text{ (stat)} \pm 0.08 \text{ (syst)}$$

The significance is 3.1σ including systematic uncertainties

$B^0 \to \rho^0\rho^0$

Pit Vanhoefer

- Important final state in combination with the other ρ charge states
- very difficult, since small branching ratio and large backgrounds
- strong correlations between fit variables observed



- special generator written to master interferences between various 4 pion final states

$$Br(B^0 \to \rho^0\rho^0) =$$

$$(1.06 \pm 0.32) \times 10^{-6}$$

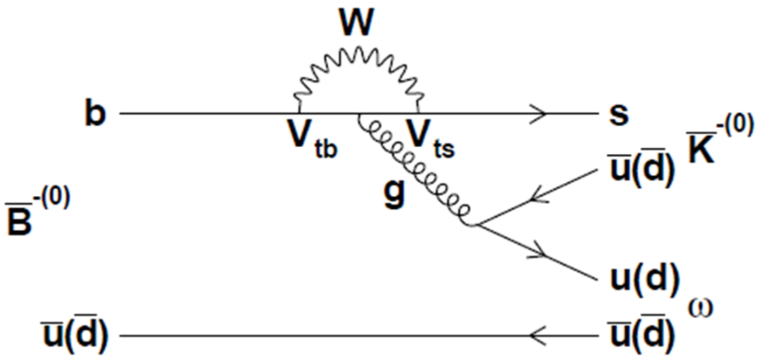
$$f_L = 0.38 \pm 0.16$$

🟥 signal

🟨 4 pion background

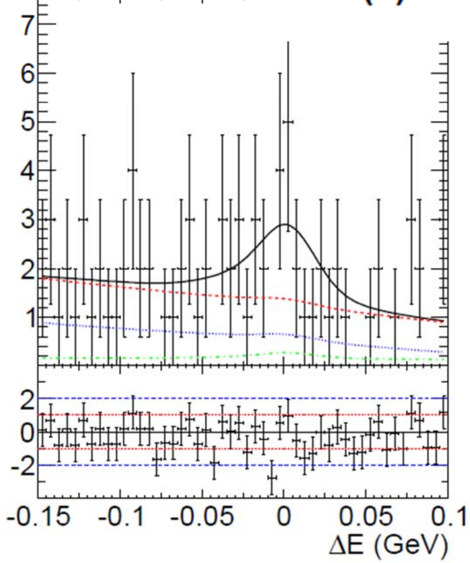
🟩 Background from $B^0\overline{B}^0$

$B^0 \to \omega K_S$ (analysis on Φ_1 (β) consistency)



loop diagram dominates, sensitive to New Physics

Analysis with improved method for background suppression



$$\mathcal{B}(B^0 \to \omega K^0) = (4.9^{+1.3}_{-1.1}\,(\text{stat})) \times 10^{-6}$$

$$\tau_{B^0} = 1.22 \pm 0.35 \text{ ps}$$

Result from 155 M out of 772 M B-events (diploma thesis of Veronika Chobanova)

$$\mathcal{B}(B^0 \to \omega K^0) = (5.0 \pm 0.6) \times 10^{-6}$$

$$\tau_{B^0} = 1.519 \pm 0.007 \text{ ps}$$

world average

expected at full statistics

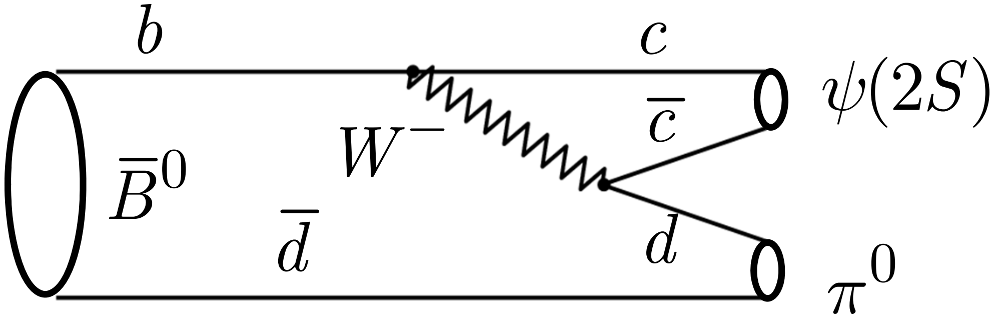
Physics observable statistical uncertainty	Previous Analysis	MPI
$\delta\mathcal{B}(B^0 \to \omega K^0_S)$	13%	9%
$\delta\mathcal{A}_{CP}(B^0 \to \omega K^0_S)$	0.24	0.19
$\delta\mathcal{S}_{CP}(B^0 \to \omega K^0_S)$	0.38	0.28

Analyses in Progress: Tree vs. Penguin

Elena Nedelkovska

$B^0 \rightarrow \psi(2S)\pi^0$

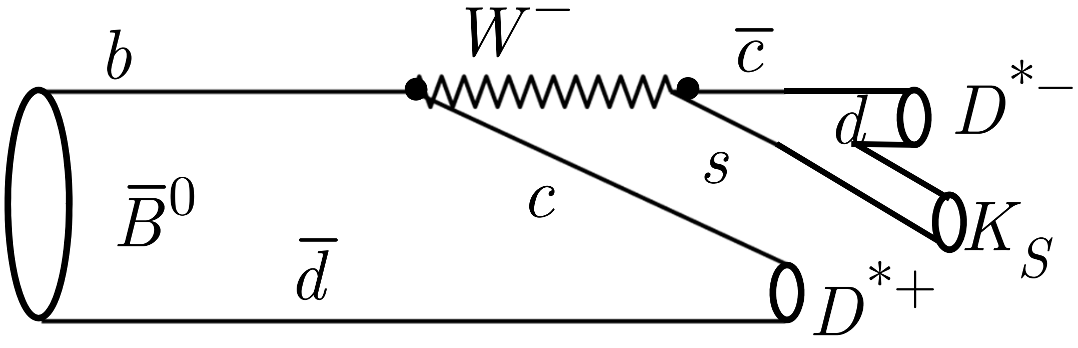
color/Cabibbo-suppressed tree,
check penguin contamination
in $B^0 \rightarrow J/\psi\, K^0$ (will be first measurement in Belle)



Martin Ritter

$B^0 \rightarrow D^{*+}D^{*-}K_S$

lift sign ambiguity for Φ_1,
(ideal to test new low p_T pion
finding algorithms)



- General conclusion on „MPI-type“ analyses of Indirect CP violation: strongest group in this area within Belle
  methods have been proven to work: smaller uncertainties obtained !

SuperKEKB and Belle II

1.7 A e^-
1.4 A e^+

Belle-II Collaboration founded in Dec. 2008
now over 420 members from
58 institutions and 14 countries,
strong European participation:
Austria, Germany, Czech Republic,
Poland, Spain, Slovenia,
(mainly in Pixel Vertex Detector,
Si Strip Detector)

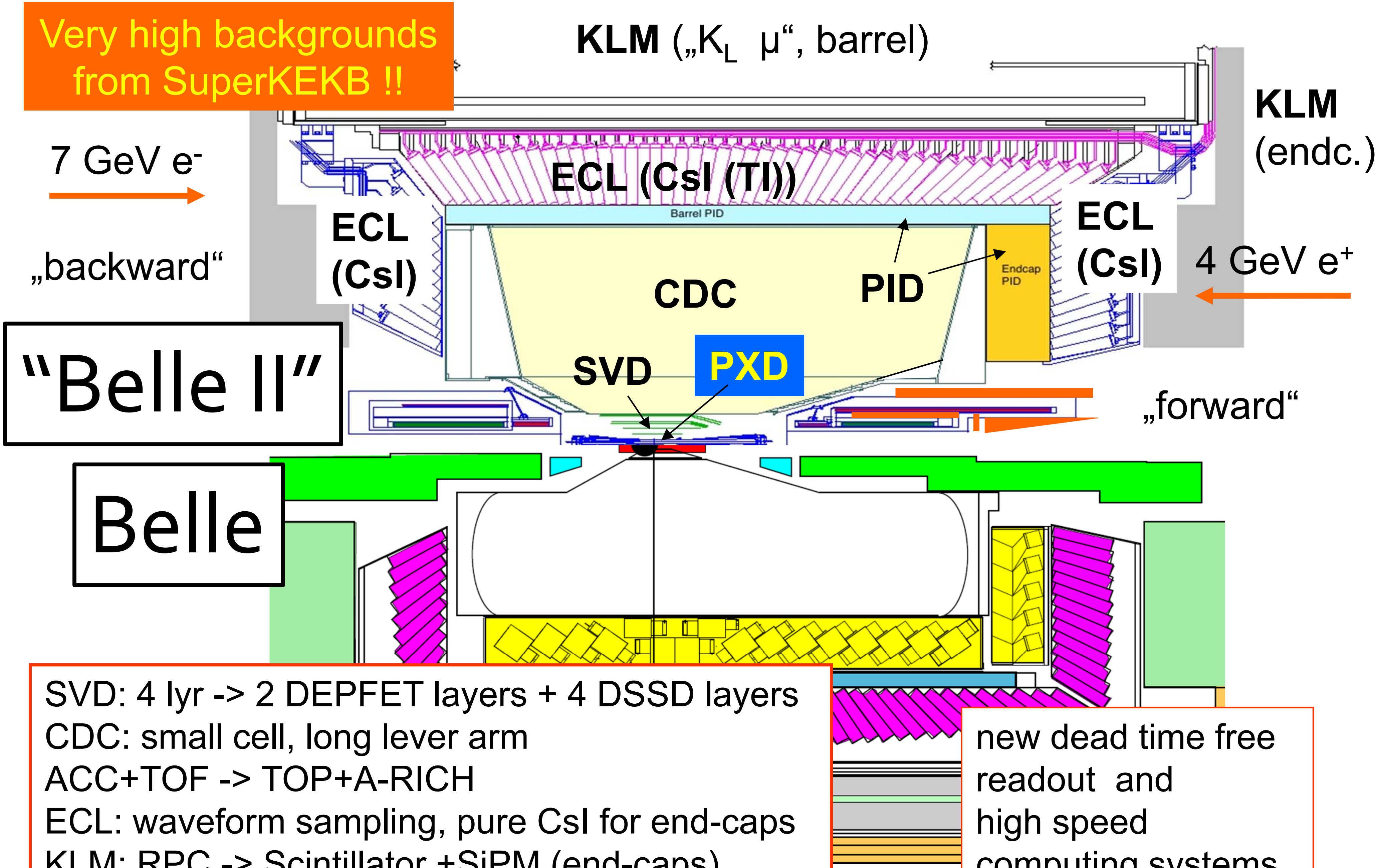
PXD (DEPFET) project led by MPI

SuperKEKB: increase instantaneous
luminosity by a factor of 40 (->$8x10^{35}$)

Project fully approved
Last step taken: Parliament (End of March,2011)

Detector: Baseline Design

Very high backgrounds
from SuperKEKB !!



SVD: 4 lyr -> 2 DEPFET layers + 4 DSSD layers
CDC: small cell, long lever arm
ACC+TOF -> TOP+A-RICH
ECL: waveform sampling, pure CsI for end-caps
KLM: RPC -> Scintillator +SiPM (end-caps)

new dead time free
readout and
high speed
computing systems

DEPFET-Collaboration @ Belle II

Original Collaboration: DEPFET pixel detector @ ILC (since 2002)
Since 2008: Unite efforts to deliver the PXD by 2015 for Belle II

IHEP Beijing, China
Charles University, Prague, Czech Republic
DESY Hamburg (C. Niebuhr)
University of Bonn (N. Wermes, H. Krüger)
University of Heidelberg (P. Fischer, I. Peric)
University of Giessen (W. Kühn, S. Lange)
University of Göttingen (A. Frey)
University of Karlsruhe (T. Müller, M. Feindt)
Ludw.-Max.-University, Munich (J. Schieck)
Max-Planck-Institute for Physics, Munich
Technical University, Munich (S. Paul)
IFJ PAN, Krakow, Poland
University of Barcelona, Spain
CNM, Barcelona, Spain
IFCA Santander, Spain
IFIC, Valencia, Spain

DEPFET@Belle II

Management:

- Project Leader
  C. Kiesling (MPI)
- Technical Coord.
  H.-G. Moser (MPI)
- IB- Board
  Chair: Z. Dolezal (Prag)
- Integration Coordinator
  Shuji Tanaka (KEK)

Recent Developments

„PXD“

- **DESY group** interested in thermo-mechanical work packages:
  (physicists + 1.5 FTE in engineering manpower)
  cooling units, mockups for PXD, SVD, beampipe, installation
  Meeting at MPI with Krakow, Valencia, Vienna
  (+ tracking, alignment, computing …)

- **Grounding Schemes (PXD and Belle II)**
  MoU signed with ITA (Spain) on electrom. compatibility (PXD)

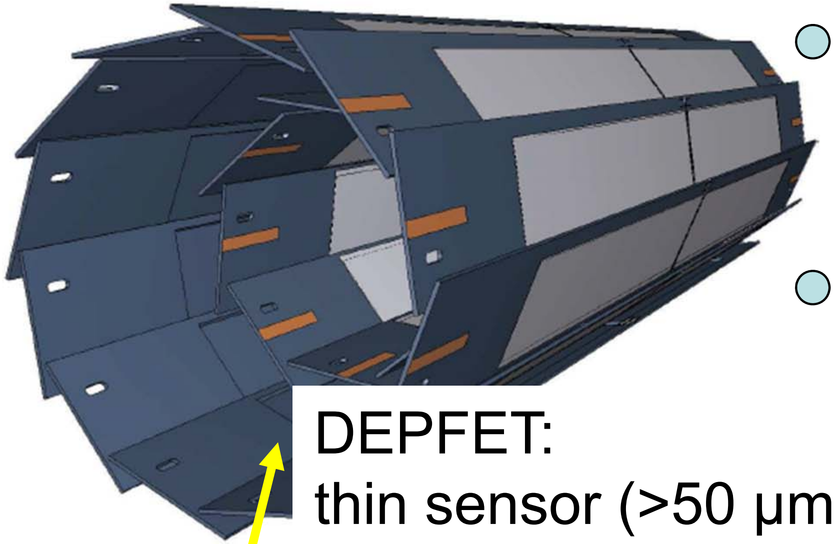
„Belle II “

- **TUM/fortiss informatics**
  A. Knoll’s group interested in slow control system of the
  CO2 plant and of the slow control of Belle II in general
  (Meeting at CERN with ATLAS, LHCb)

- **Interest** of Heidelberg physics group (K. H. Meier) to collaborate
  on a possible level-1 CDC z-vertex trigger
  Idea: veto events with tracks outside the interaction region
  method: algorithm on neuromorphic hardware

Silicon Tracking System @ Belle II

SuperKEKB: Nano beam option, 1 cm radius of beam pipe

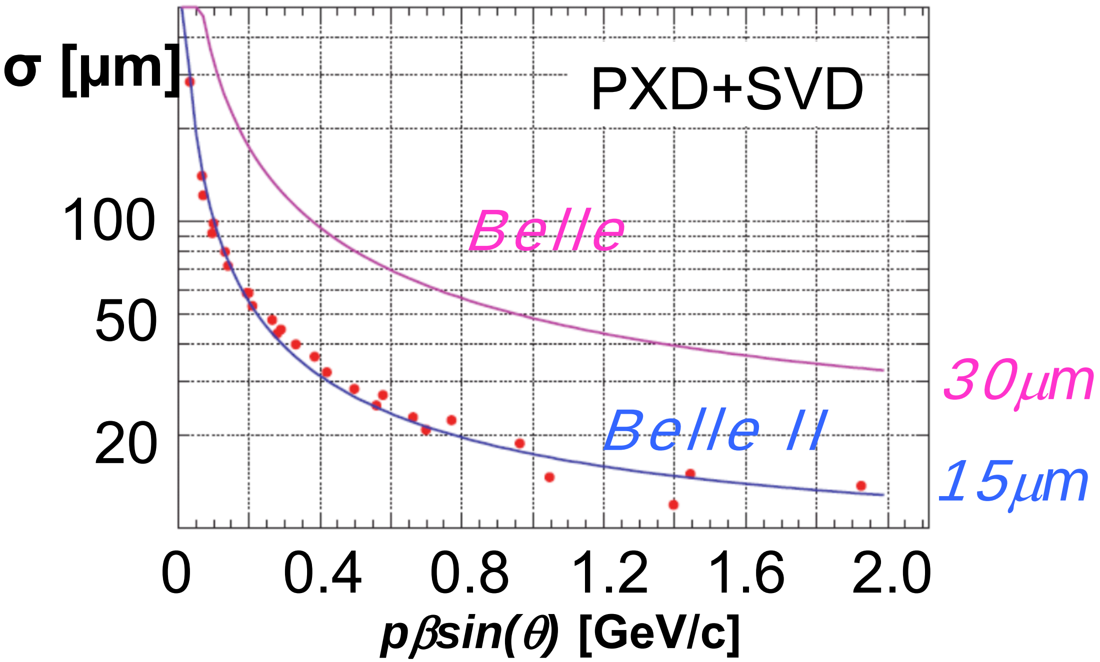


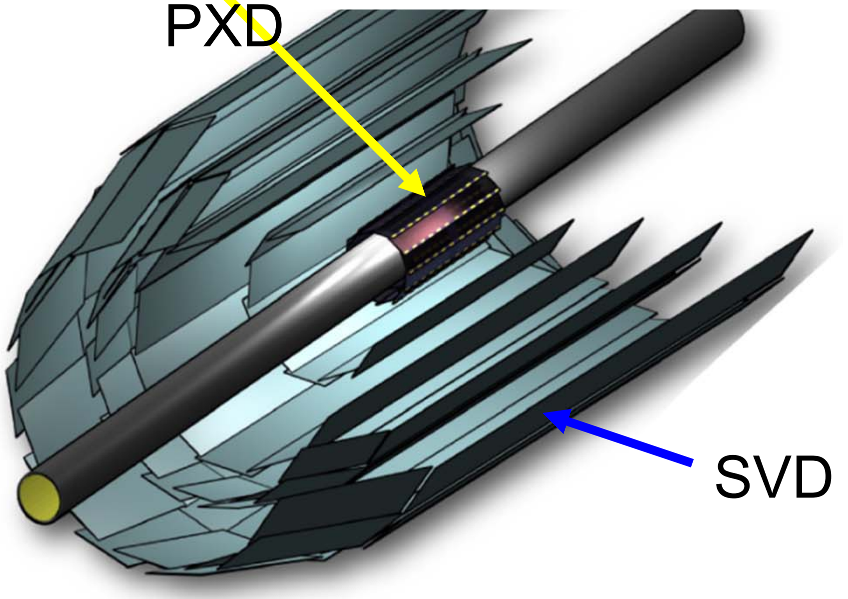
„PXD“

- 2 layer Si pixel detector (DEPFET technology)
  (R = 1.4, 2.2 cm) monolithic sensor
  thickness 75 μm (!), pixel size ~50 x 60 μm²
- 4 layer Si strip detector (DSSD) ← „SVD“
  (R = 3.8, 8.0, 11.5, 14.0 cm)

DEPFET:
thin sensor (>50 μm)
unique worldwide

Significant improvement in z-vertex resolution



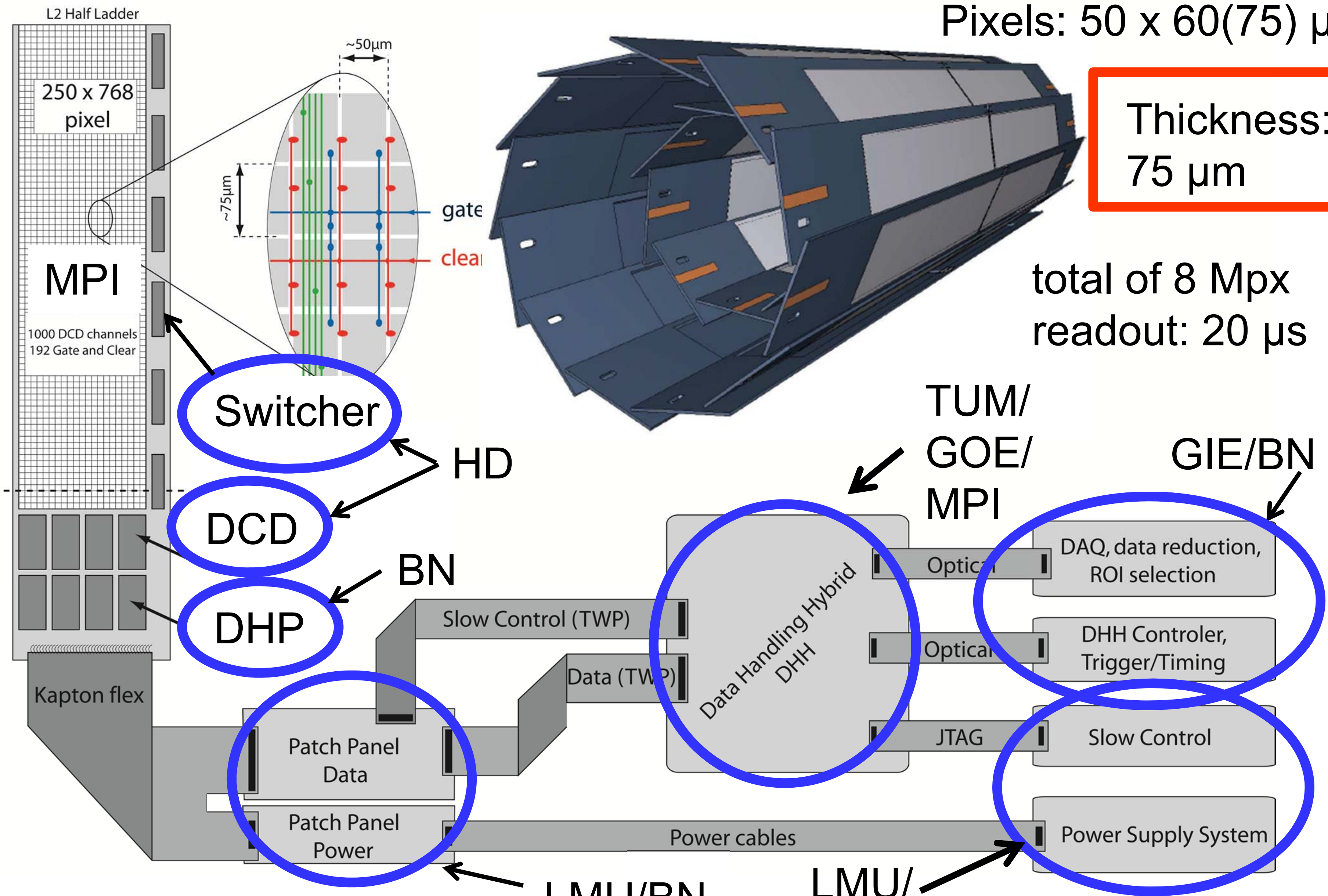


PXD Project - Layout

half ladder:
768 rows

250 cols

15 x 70 (85) mm



Pixels: 50 x 60(75) µm

Thickness: 75 µm

total of 8 Mpx
readout: 20 µs

Switcher

DCD

DHP

HD

BN

TUM/
GOE/
MPI

GIE/BN

LMU/BN

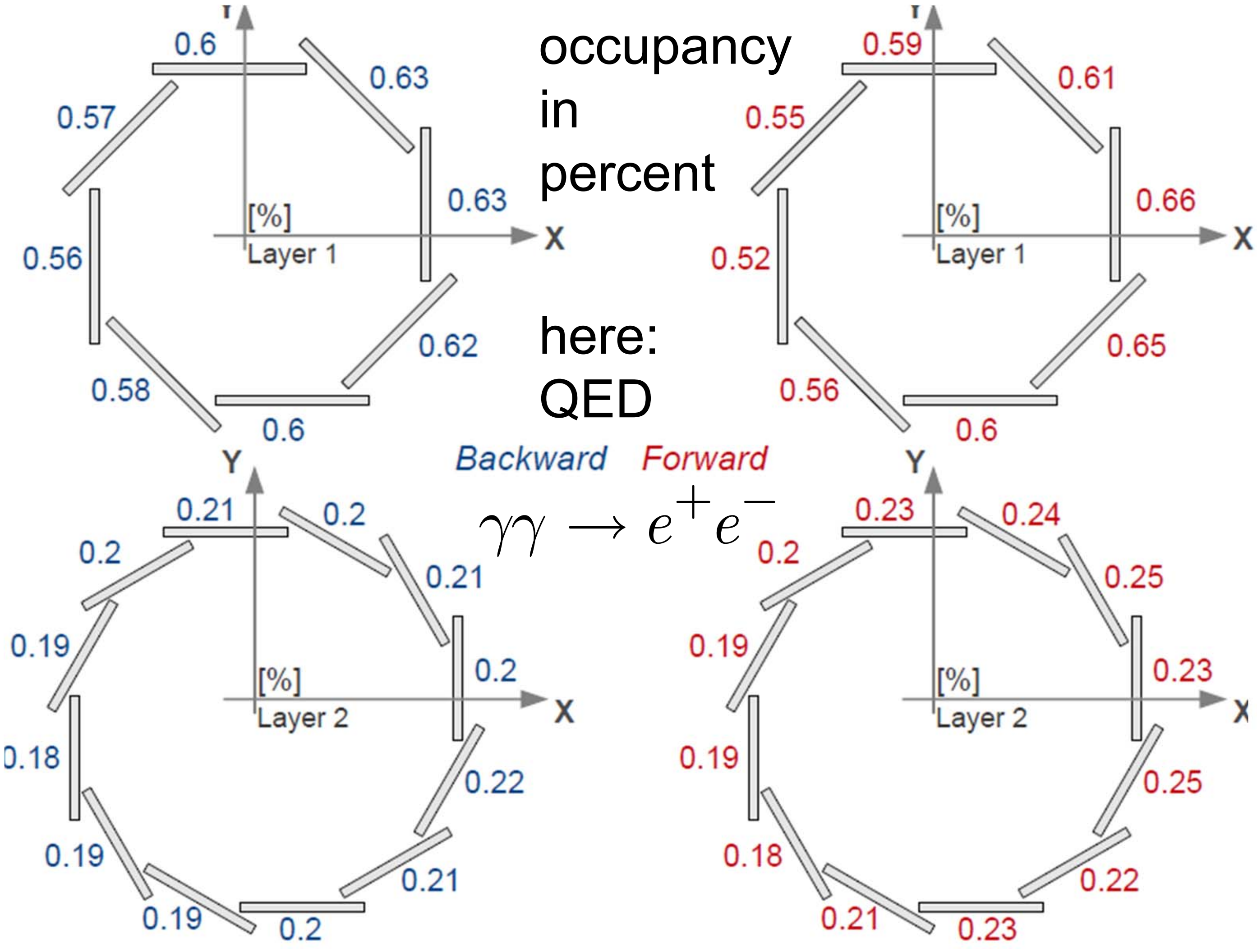
LMU/
TUM (inf)

PXD Parameter Optimization

MPI group strongly involved in the development of the BelleII software framework, essential for realistic simulations:
Andreas Moll, Martin Ritter, Kolja Prothmann, Susanne Koblitz

occupancy in percent

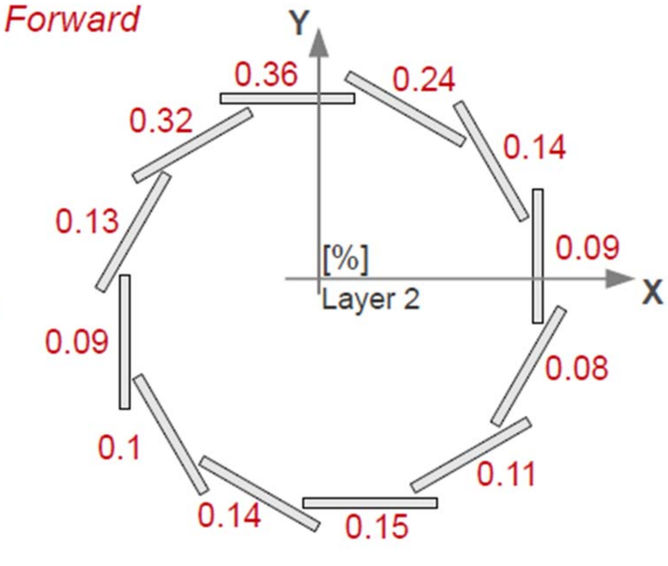
here: QED



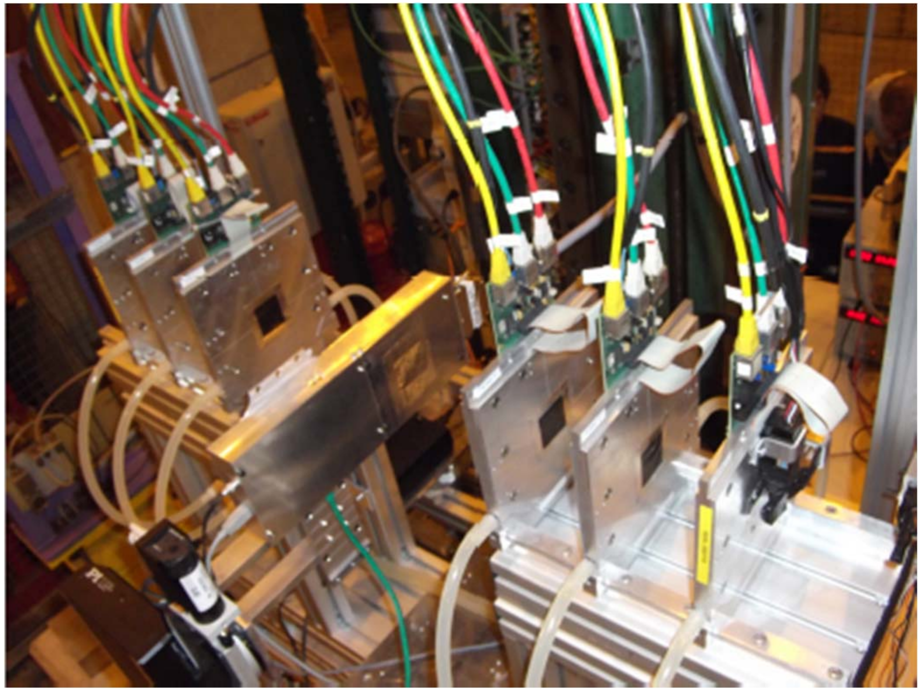
$$\gamma\gamma \rightarrow e^+e^-$$

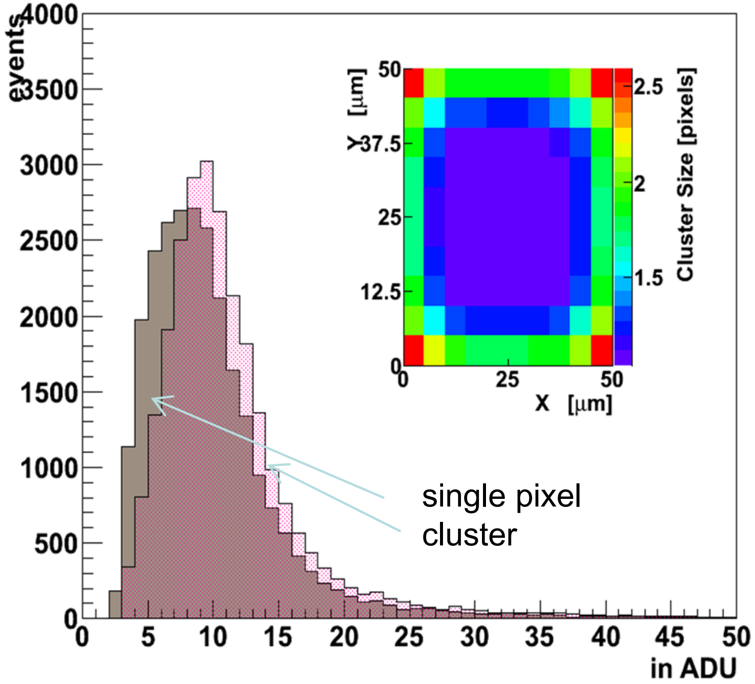
Full Geant4 detector simulation

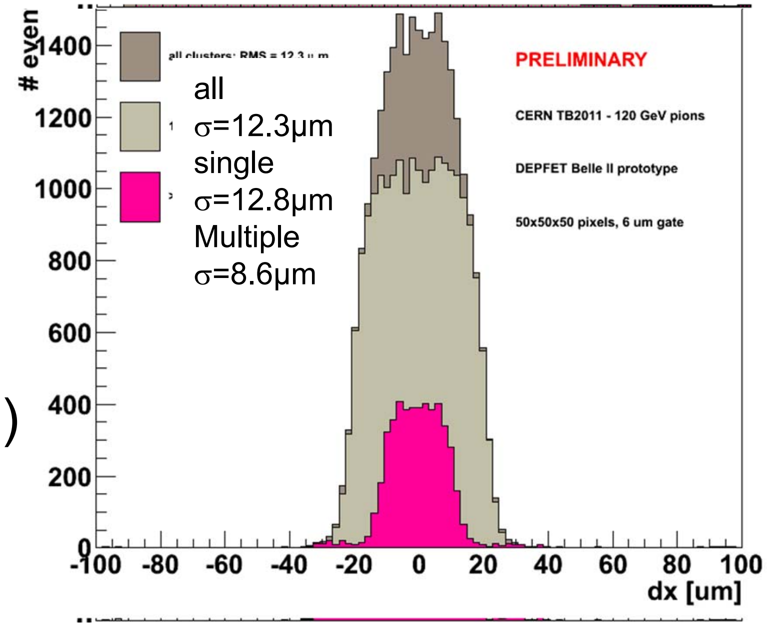
occupancy from Touschek effect



First Beam Test of Thinned DEPFET Sensors







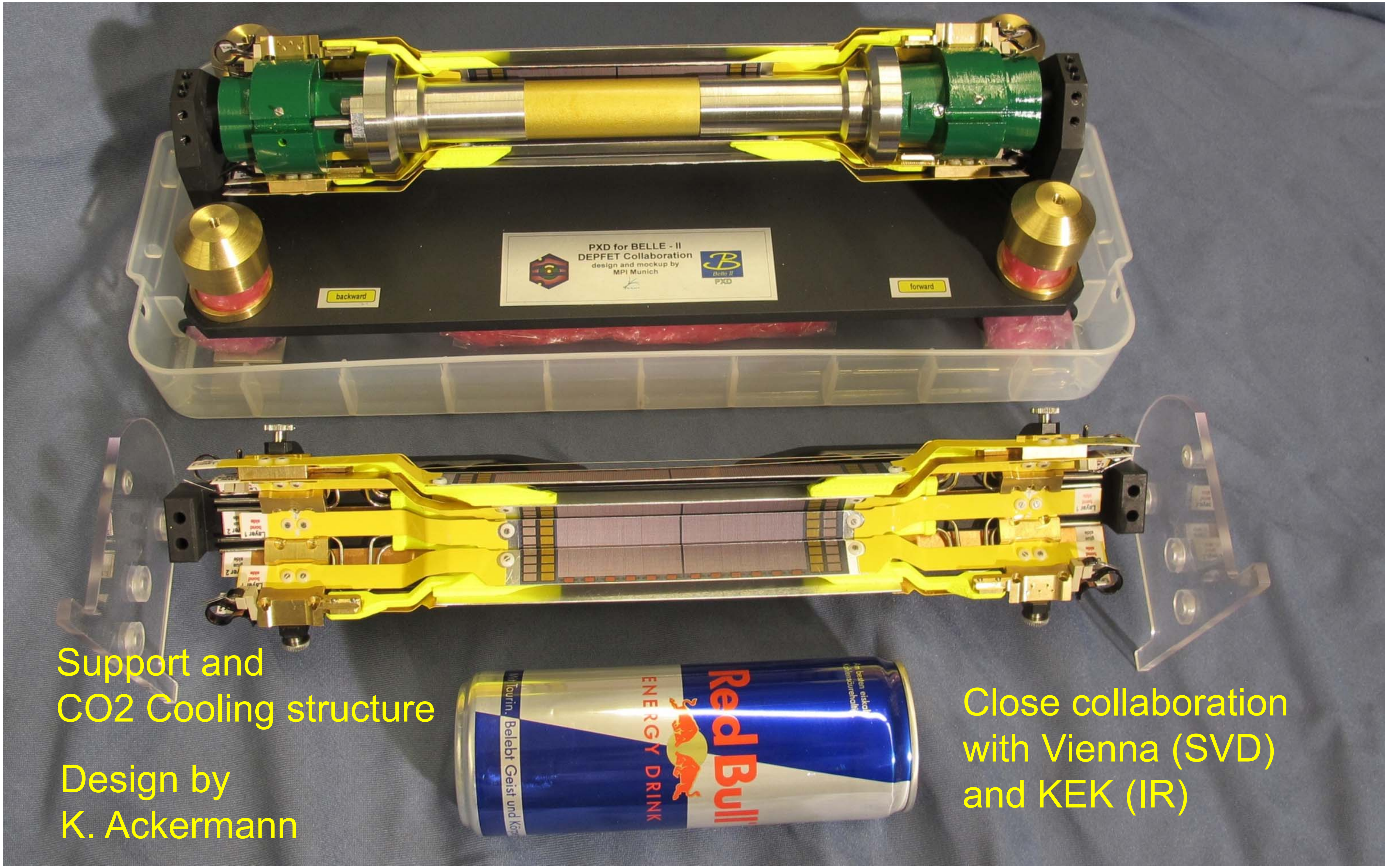
120 GeV pion beams, CERN, Oct. 2011

a) PXD6, 50μm, L=4μm, standard ox: S/N ~ 40
b) PXD6, 50μm, L=6μm, thin ox: S/N ~ 20
thin oxide not yet optimized => smaller S/N
=> S/N > 40 expected for optimal settings

Readout speed up to 320 MHz (100ns readout time)

further details: see HLL presentation (H.G. Moser)

Mechanics and Cooling



Support and
CO2 Cooling structure

Design by
K. Ackermann

Close collaboration
with Vienna (SVD)
and KEK (IR)

Status of CO2 Cooling

- Build a closed CO2 System for PXD and SVD at MPI with the help of Nikhef/CERN, Vienna, Karlsruhe, now also of DESY

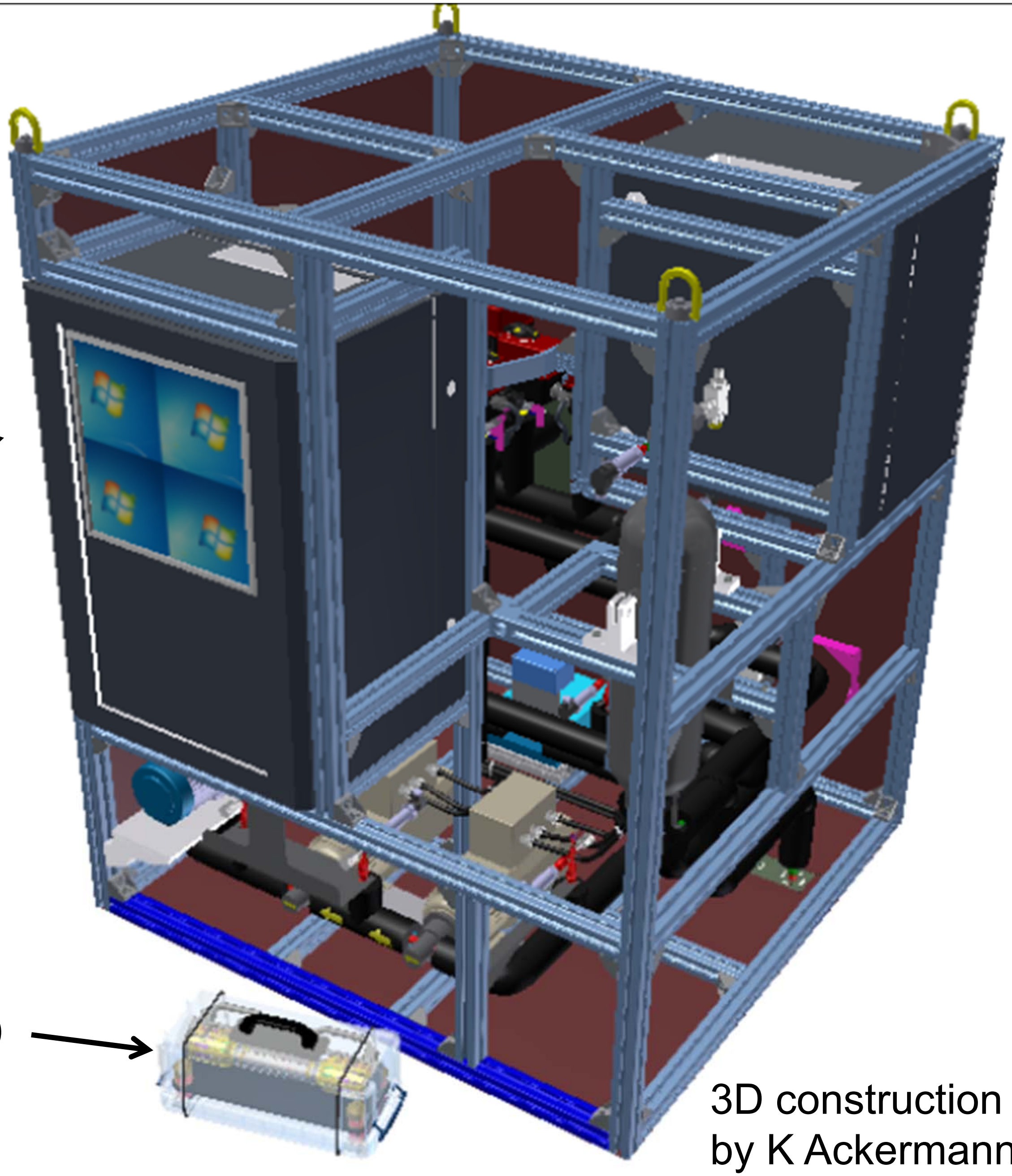
- Final goal: IBBelle (for ATLAS IBL and Belle II): 2kW unit

- Prototype:
  MARCO (Multipurpose Apparatus for Research on CO2): 1kW unit
  - design of MARCO is finalized (K. Ackermann)
  - frame done at CERN by M. Lippert
  - transport to Munich: 20. Nov. 2011,
  - piping (orbital welding: W. Schramm, A. Wimmer) in Jan. 2012,
  - pressure tests (TÜV) in Feb. 2012
  - transport back to CERN in March 2012
  - electrical installation (MPI support) + commissioning
  - transport back to MPI by end of June 2012
    (available for long-term tests until IBBelle is built)

- build IBBelle for MPI and ATLAS (+ 2 units for KEK, probably by DESY)

CO2 Cooling (cont.)

MARCO 1 kW unit

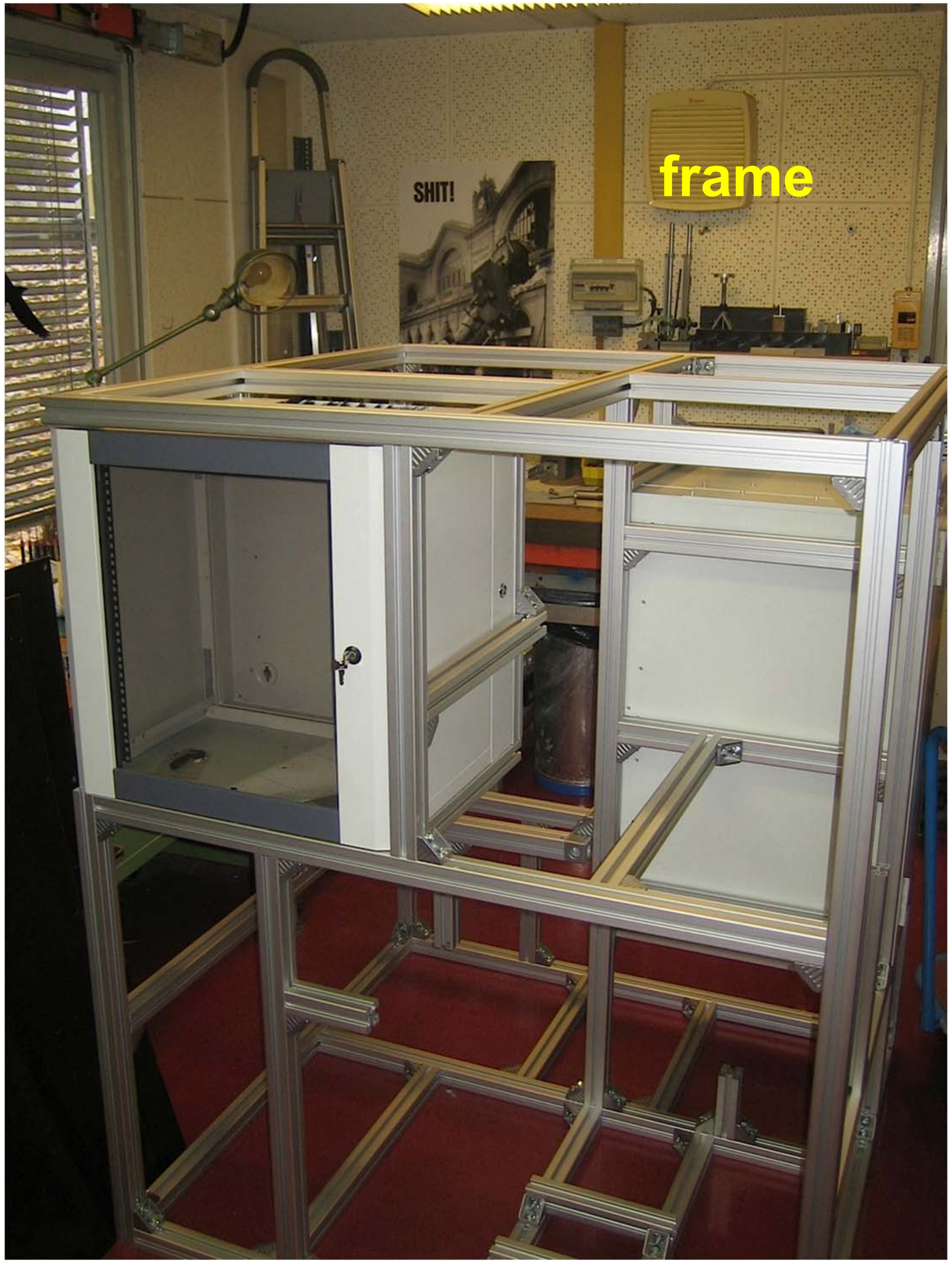


User control panel
(PVSS)

model of PXD

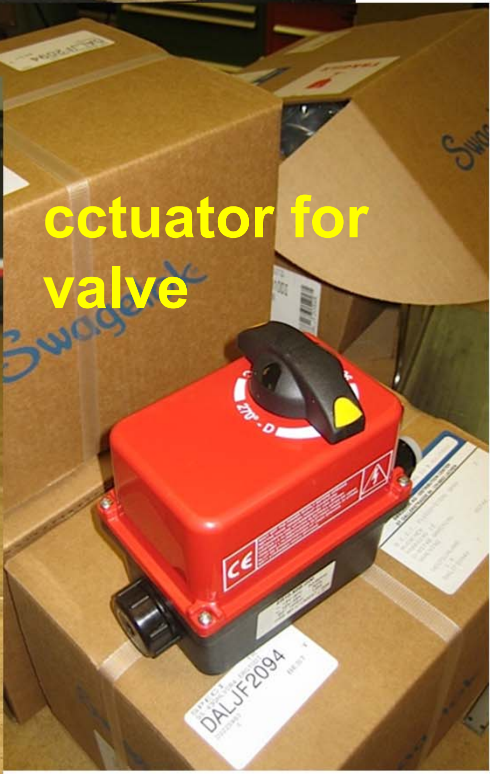
3D construction
by K Ackermann

CO2 Cooling (cont.)


frame


accumulator

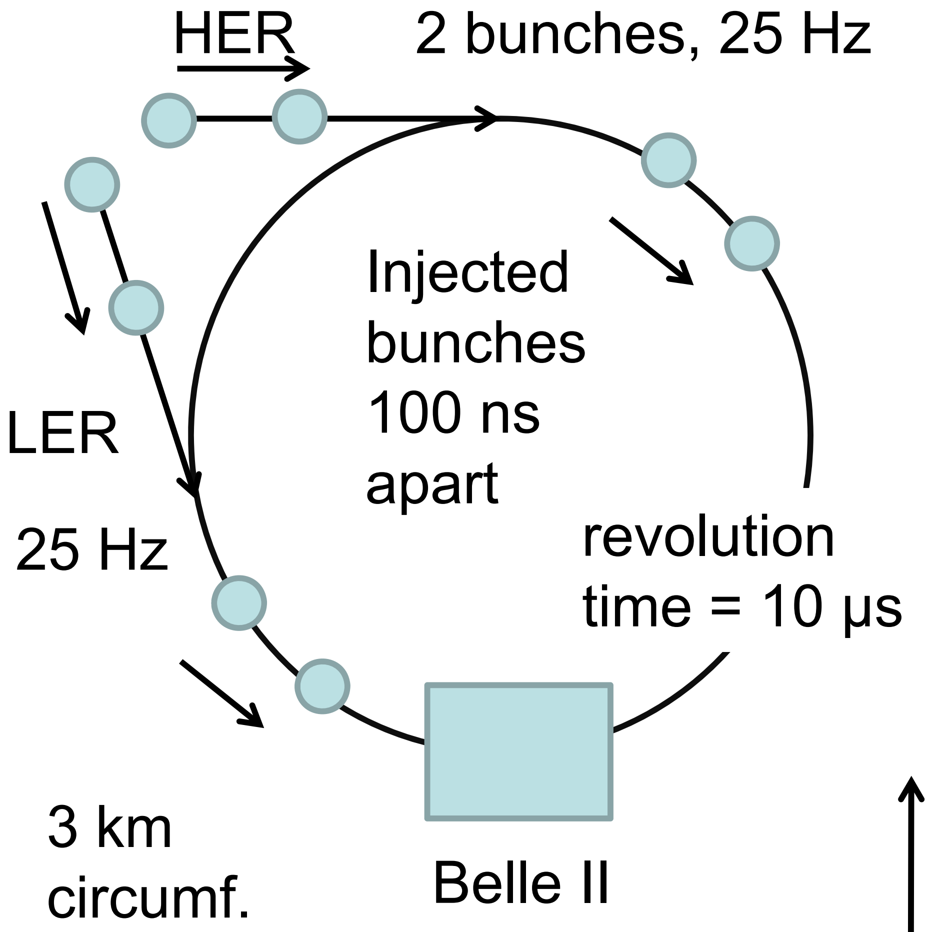

heat exchanger


cctuator for valve

Revised Schedule for the PXD Project

finish evaluation of PXD6 (test production)	Oct. 2011
start prototype (PXD9) production	Feb. 2012
finish EMCM-flip chip / electr. tests / flip chipping	Sep 2012
power / cooling / DAQ ready (prototypes)	Jan. 2013
final version of ASICs ready	Feb. 2013
Finish prototype evaluation	July 2013
start final DEPFET production	July 2013
all ASICs produced	Feb. 2014
BEAST II (rad. mon.) near beampipe ready	Oct. 2014
finish final production Batch 1	Feb. 2015
finish final production Batch 2	May 2015
power / cooling / DAQ ready (installed)	July 2015
finish assembly PXD	Aug. 2015
start integration (beampipe, SVD, power, cooling)	Sep. 2015

Problem: Injection Noise



HER

2 bunches, 25 Hz

LER

25 Hz

Injected
bunches
100 ns
apart

revolution
time = 10 µs

3 km
circumf.

Belle II

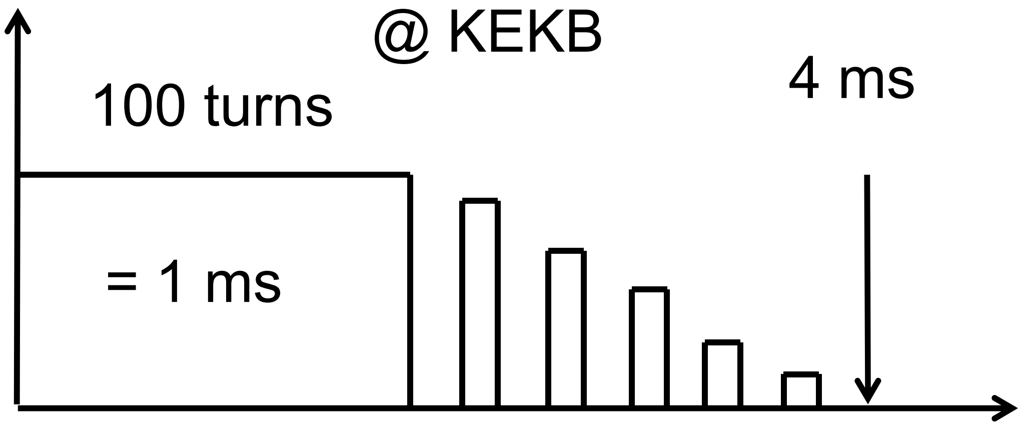
Total rate: 50 Hz

20 % deadtime for PXD

Principle:

continuous injection, developed
by KEKB machine physicists

Liouville theorem:
bunches cannot be injected into
same phase space volume
-> „cooling“ by synchrotron radiation
-> particle loss -> „noisy bunches“



@ KEKB

100 turns

= 1 ms

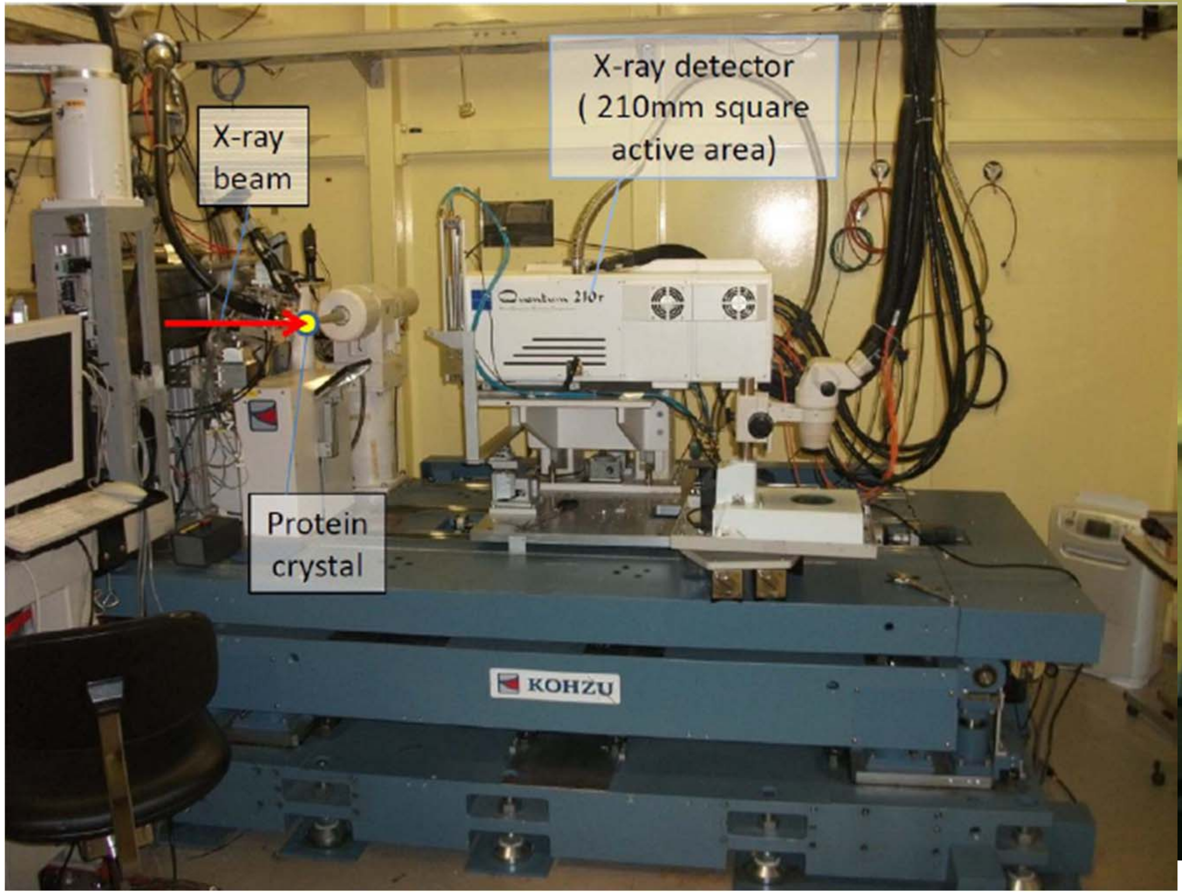
4 ms

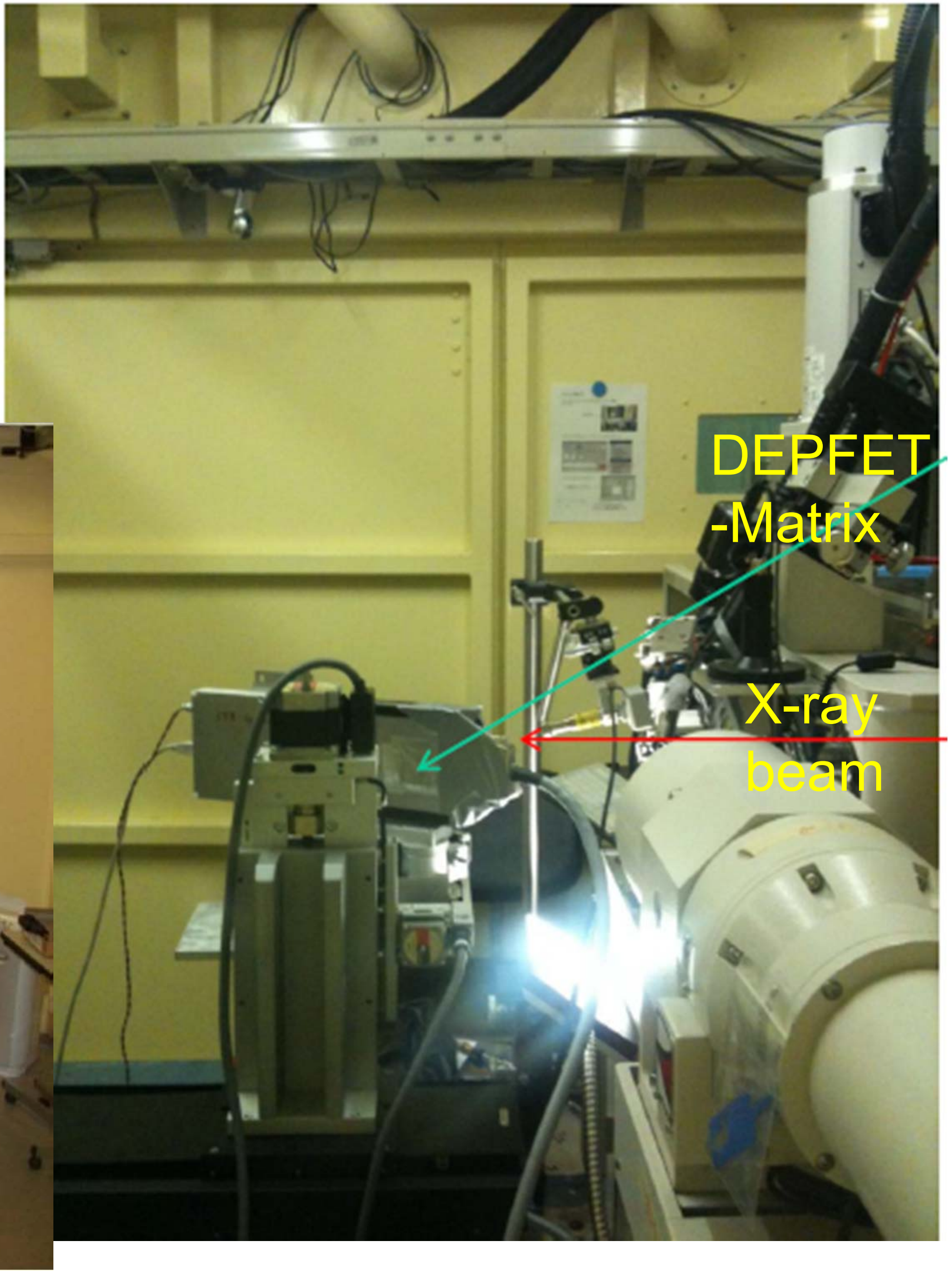
SuperKEKB: same damping assumed

First DEPFET Matrix in KEK X-Ray Beam

Sat., Nov. 20, 2011:
Experiment @ KEK Photon Factory:

BL5A: synchrotron photons between
7 and 14 keV





Summary & Conclusions

- „MPI-type“ analyses of Belle data proven to work: reduced uncertainties
- DEPFET-Collaboration (led by MPI) is growing, new member DESY, Strong support also on the engineering level (DESY).
- New groups interested to work in Belle II (TUM Informatics groups in Slow Control, Heidelberg group in CDC Trigger with neural nets)
- Significant change in the overall Belle II schedule makes it possible to introduce a prototype production for the DEPFET sensors (+ASICs)
- Schedule becomes extremely tight (two productions in series), risk of possible delay not negligible, „Plan B“ in preparation
- Some ideas to potentially mitigate injection noise, help of the machine needed. But continue to search for „own“ solutions
- Interest of KEK PF to use DEPFET sensors for bio research

Friday, Nov 18, 2011 (Ground Breaking)

Signing the Memorandum of Understanding between German Funding Agencies and KEK