Status and Plans for Hadron Structure and Spectroscopy at B-Factories and BESIII

And comparison to PANDA

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International Conference on Science and Technology for FAIR in Europe 2014
13-17 October 2o14
Worms

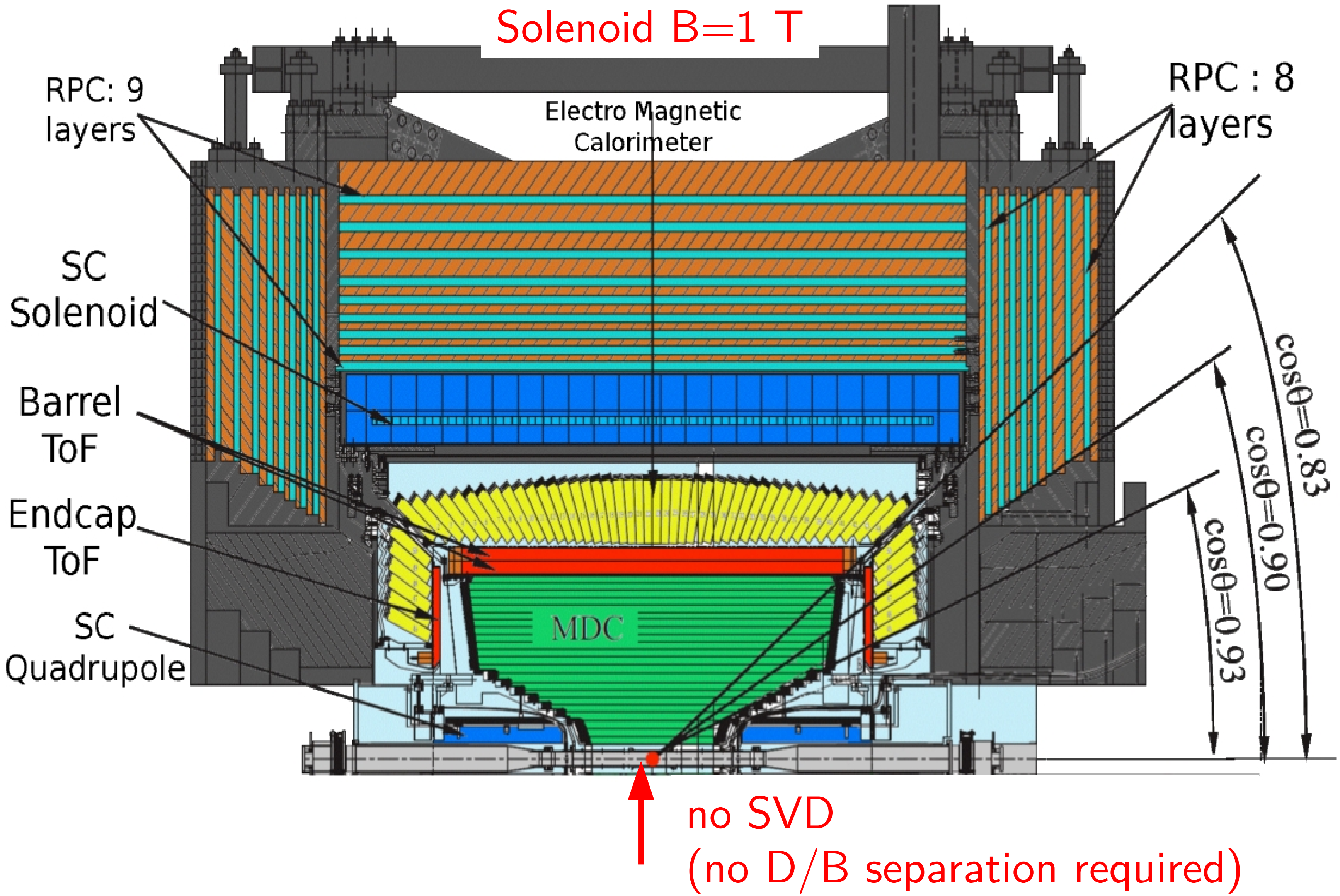
Outline

- Status of BESIII
- Status of Belle II
- Number of $c\bar{c}$ pairs per year
- 2 "benchmark" measurements
  - Charmonium(-like) States
    - X(3872), width measurement in sub-MeV regime
  - Open charm
    - electroweak physics:
      CP violation in D meson decays

- for LHCb see talk of Sebastian Neubert, TUESDAY, 10:00
- above are all PANDA long-term physics goals,
  for PANDA day-1 physics
  see talk by Paola Gianotti, THURSDAY, 10:10

BESIII Experiment

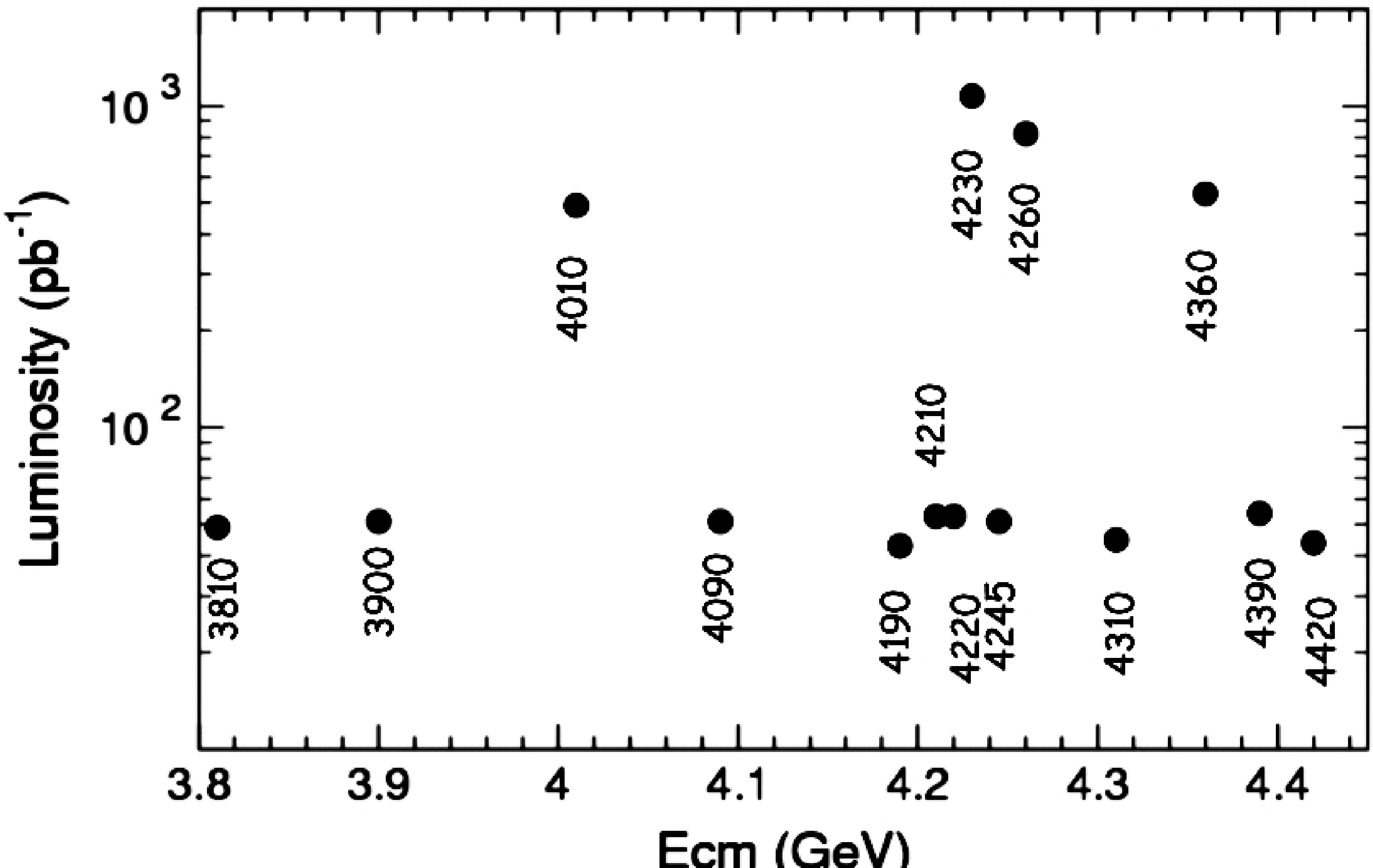
360 members, 52 institutions, 11 countries



Beijing Electron Positron Collider II

- e+e− collisions
- $2.0 \leq \sqrt{s} \leq 4.6$ GeV (charmonium regime)
  → variable beam energies
  → "tune in" on a resonance
- present luminosity $\geq 7 \times 10^{32}$ cm^{-2} s^{-1}
  ($\simeq$70% of design luminosity)
- data taking since 2009

BESIII Data Taking at different √s
(e.g. adjust beam energies)

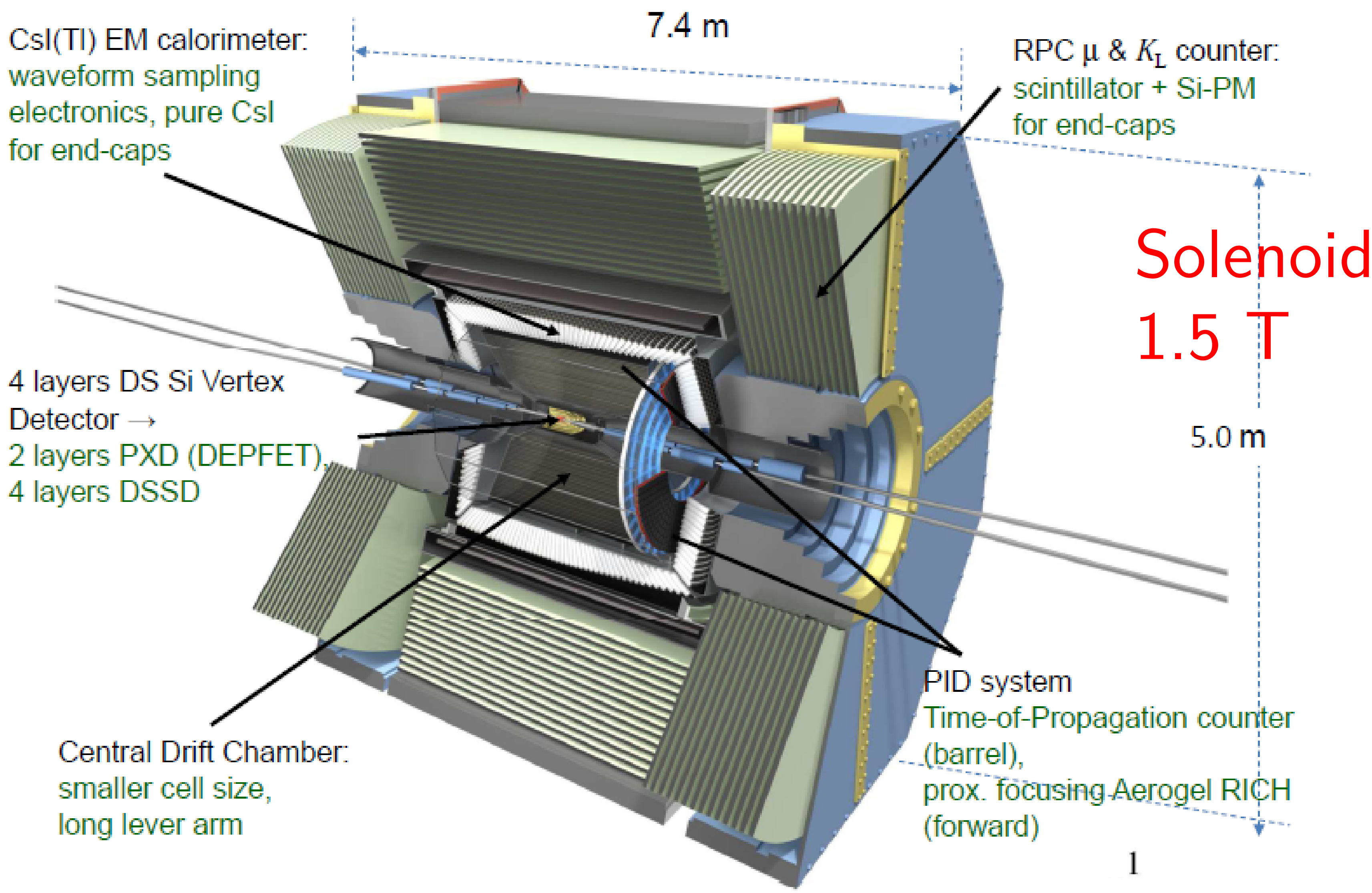


W. Gradl, MENU2013

Belle in Service Position for Upgrade to Belle II

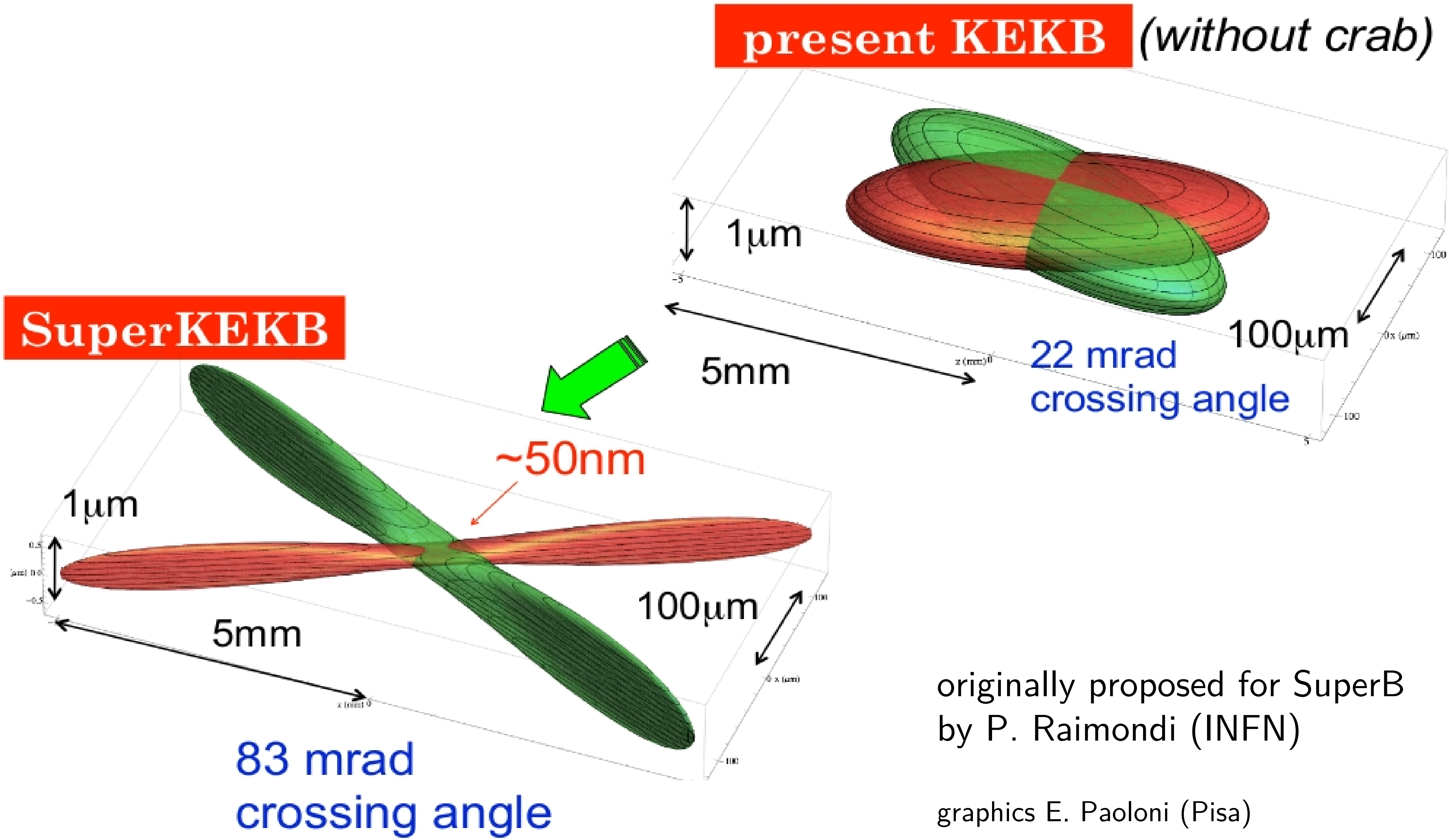
Belle II

TDR
arXiv:1011.0352



Plan: peak luminosity x 40, integrated luminosity x 50

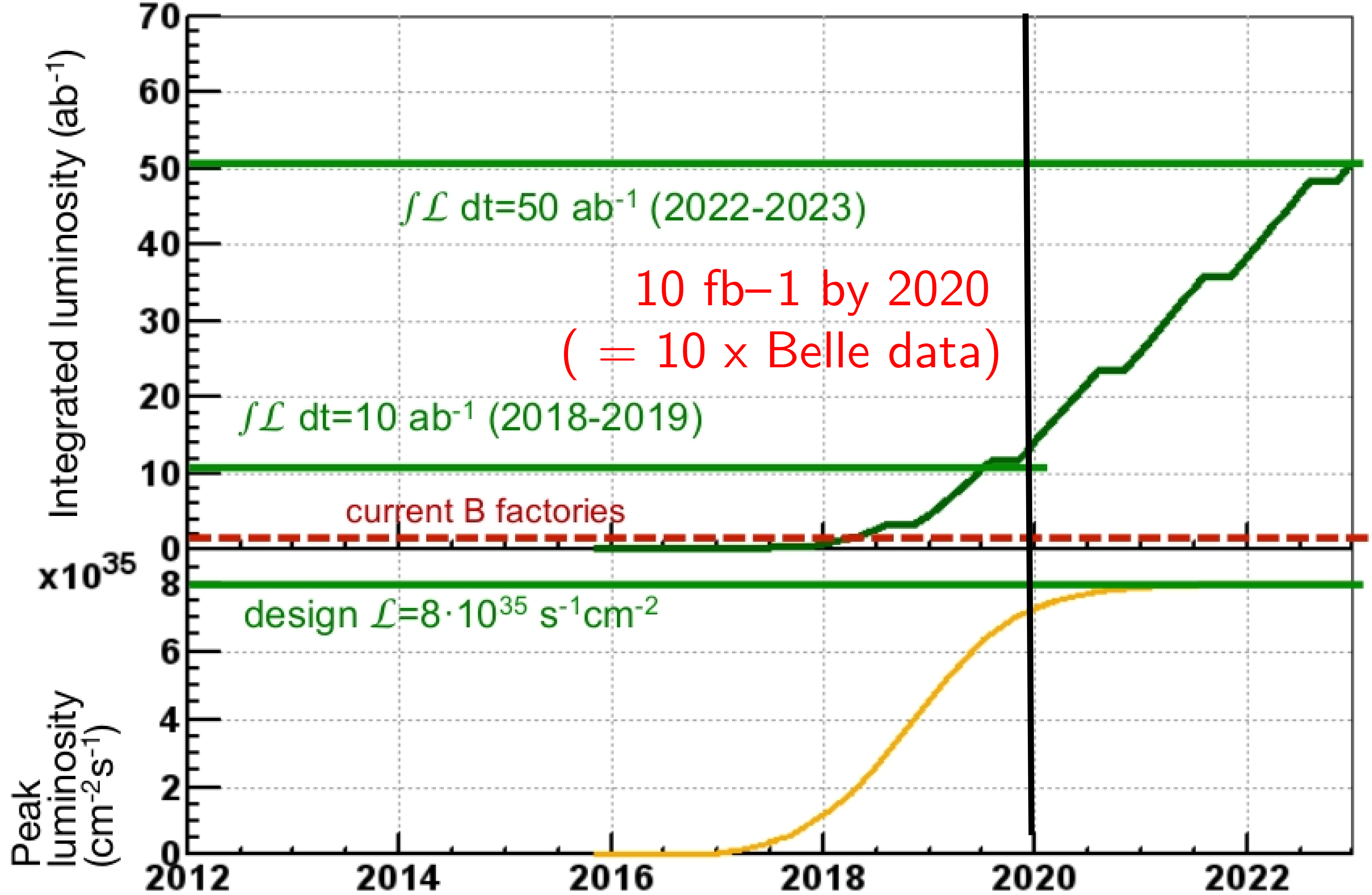
Nano-Beam Scheme



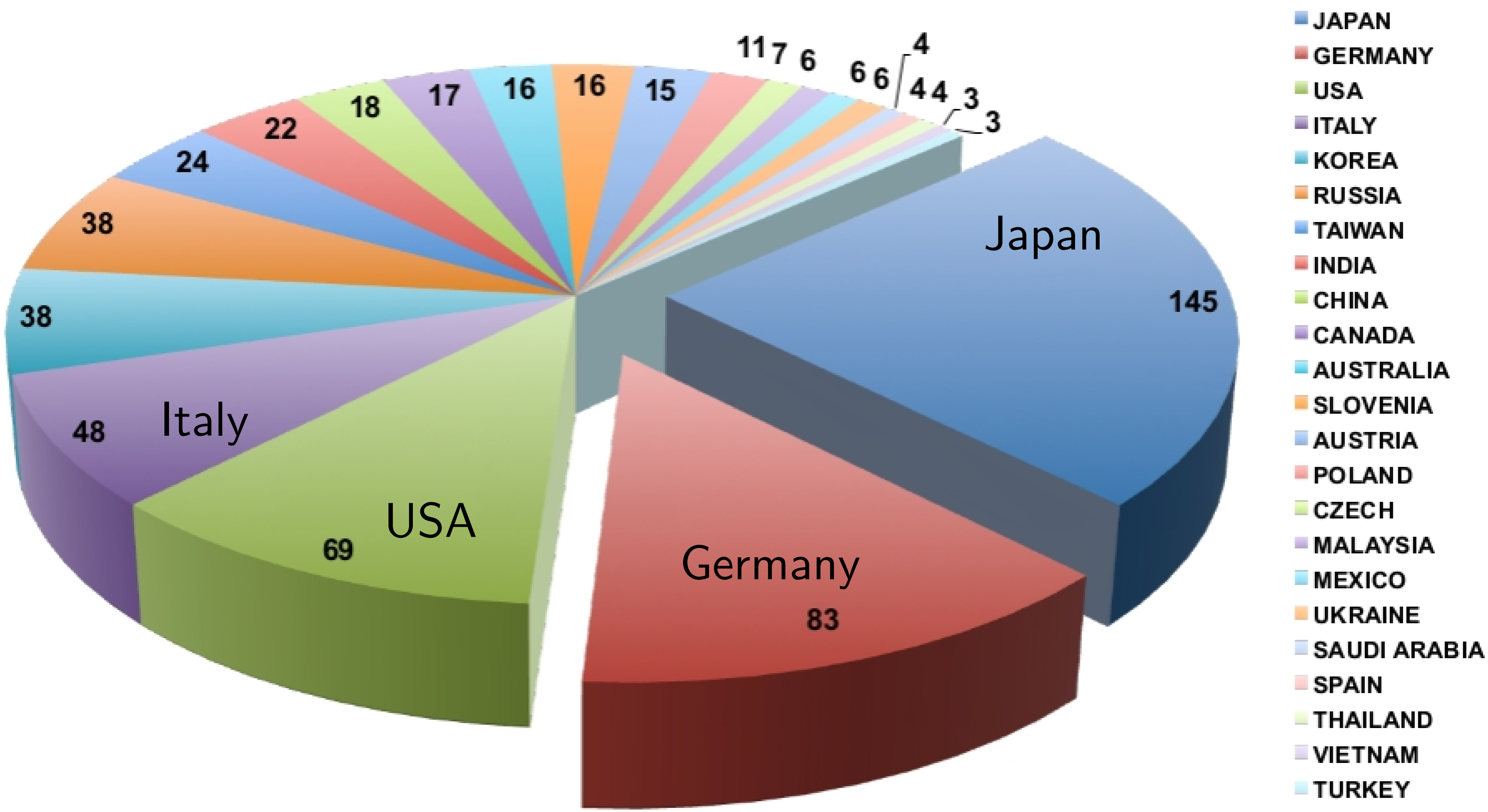
originally proposed for SuperB
by P. Raimondi (INFN)

graphics E. Paoloni (Pisa)

SuperKEKB Luminosity Projection



Belle II Collaboration



2nd largest group in Belle II

Belle II

Bundesministerium
für Bildung
und Forschung

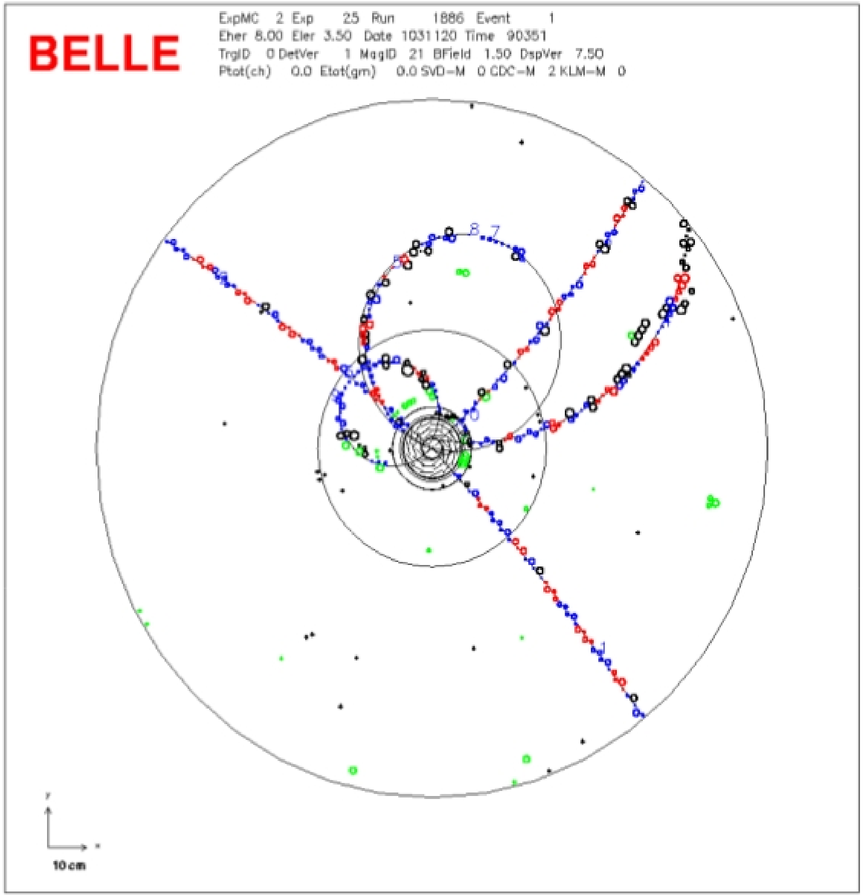
Belle II DEPFET Pixel Detector

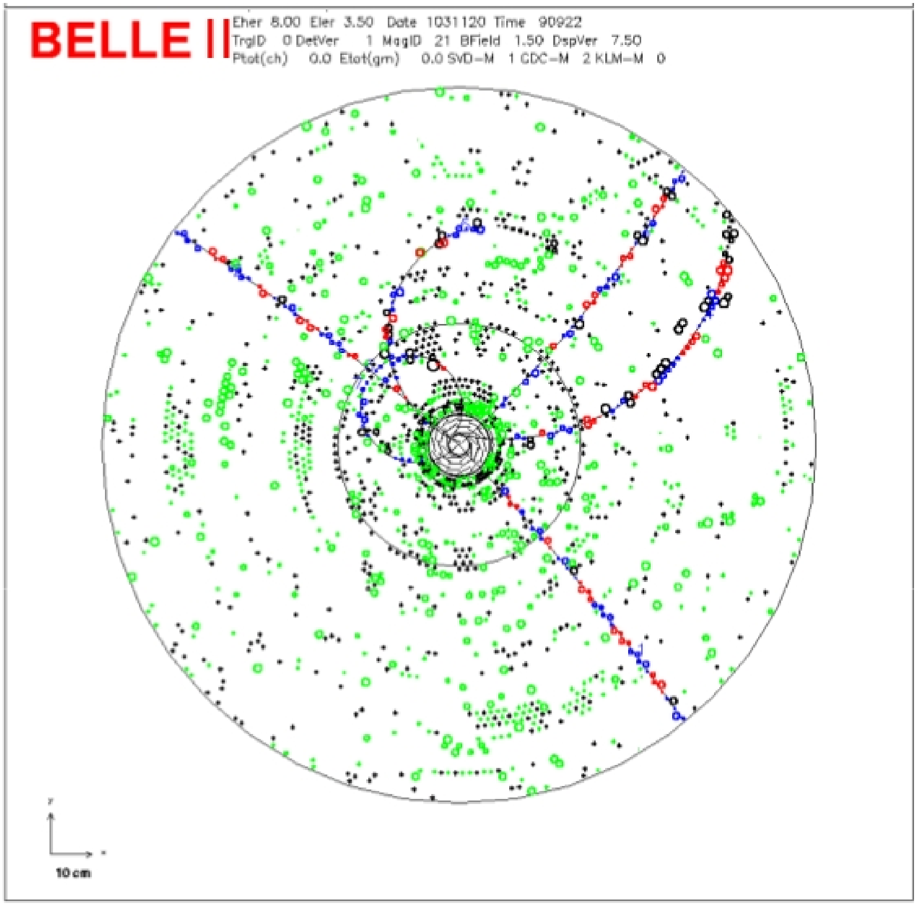
Univ. Bonn, DESY, Univ. Giessen, Univ. Göttingen, Univ. Hamburg, Univ. Heidelberg, KIT Karlsruhe, Univ. Mainz, HLL München, MPI München, LMU München, TU München

Status of Belle II

- e^+e^- collisions
- $9.4 < \sqrt{s} < 11.0$ GeV (bottomium regime)
- asymmetric beam energies e– 7.0 GeV, e+ 4.0 GeV
- charmonium production:
  - B meson decays
  - direct $e^+e^- \to c\bar{c}X$
  - initial state radiation e^+e^- ($\sqrt{s}\sim10$ GeV)$\to \gamma_{ISR}\, c\bar{c}$ ($m\sim4$ GeV)
- present schedule: physics data taking w/ full detector: 10/2017
- monitored by BPAC, 1–2 reviews per year
- new vertex detector (PXD+SVD) improves vertex resolution in beam direction 50 um $\to$ 25 um
- when Panda starts, Belle II will be running already 2–3 years assume 10 fb^{-1} in 2020

Background increase x factor 10–20





Installation of 100 new LER Dipole Magnets

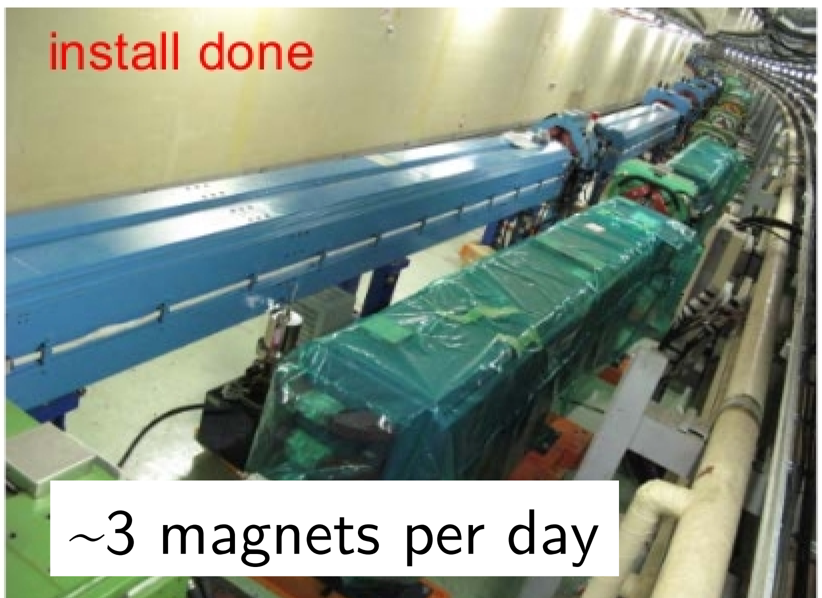
field measurement

move into tunnel

Installation of 100 new LER bending magnets done

carry on an air-pallet

Install over HER magnets



B-KLM Installation

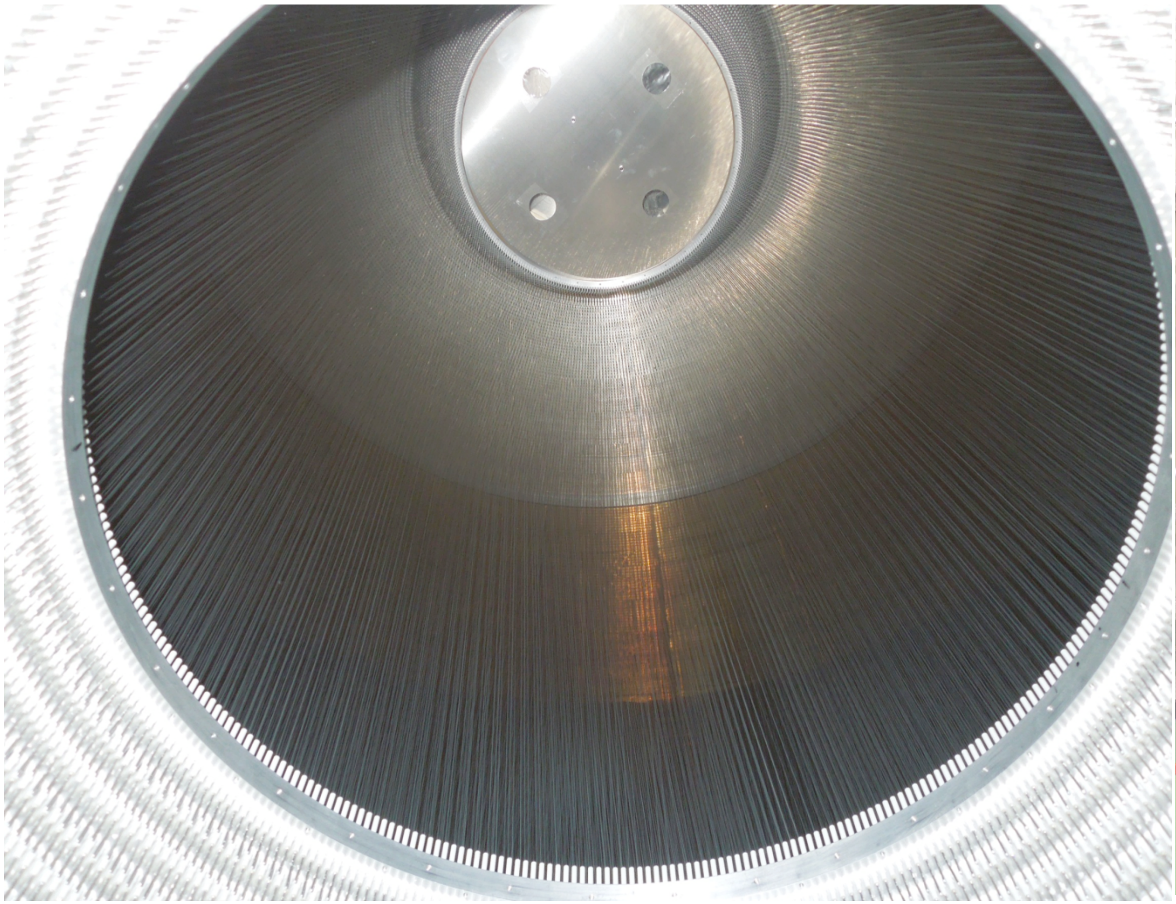
Completed on November 16^{th}

~2 months delay

During installation, modules have been checked, found to be healthy.

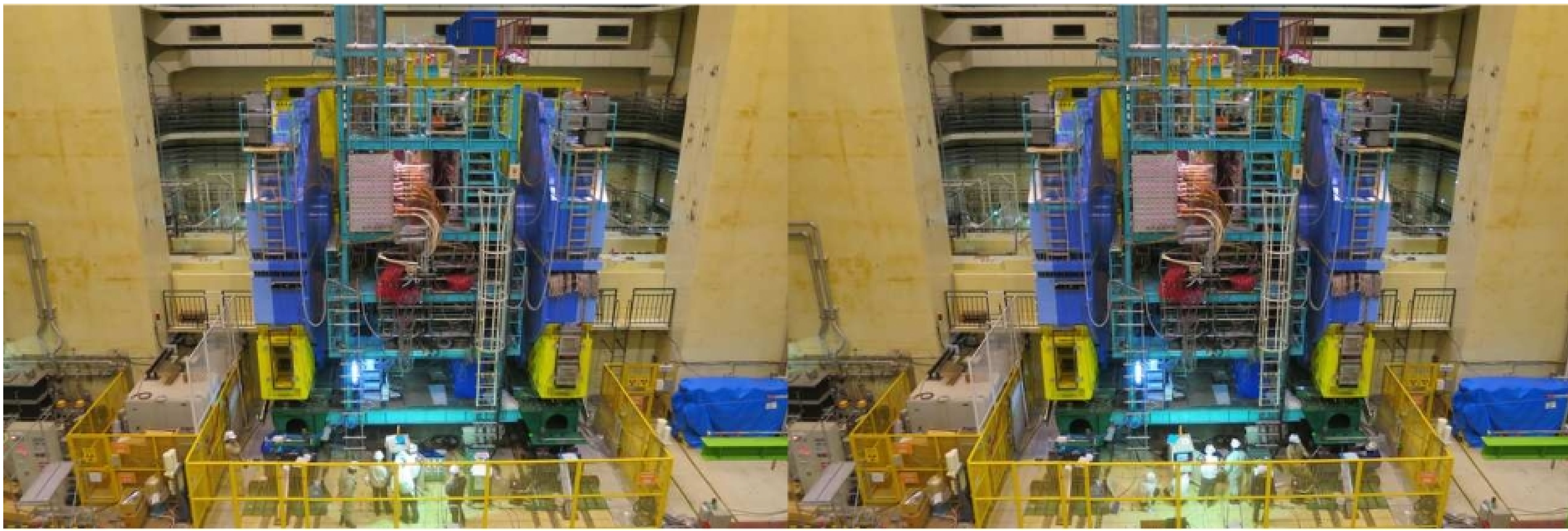
The 1^{st} New Detector Installed !!

CDC wire stringing finished (01/2014)
51456 wires



Belle Rotation 03/2013

for larger crossing angle 22 mrad $\rightarrow$ 83 mrad (nanobeam)



18.6 cm @ end of platform (accuracy 0.5 mm)

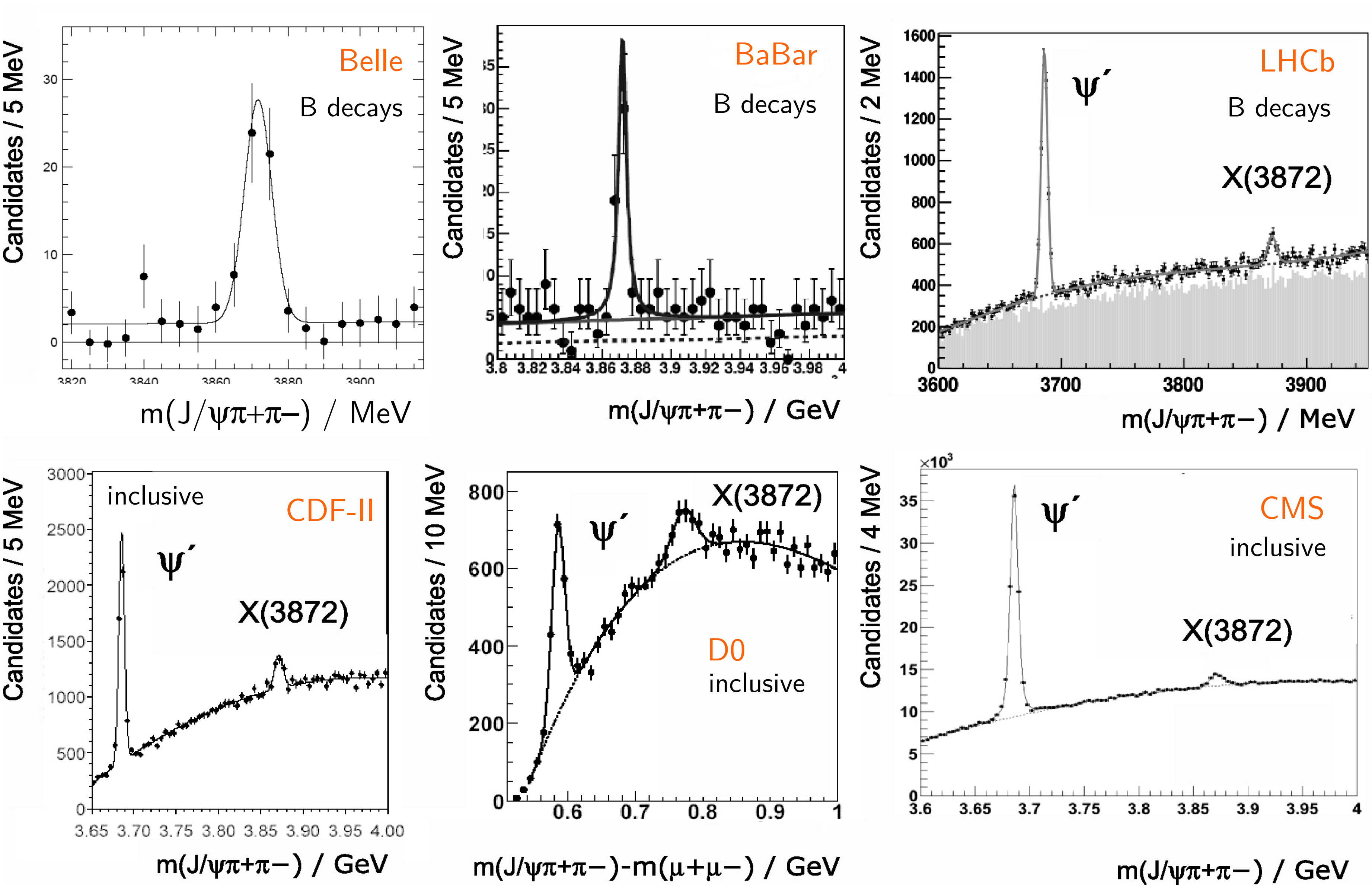
Number of $c\bar{c}$ pairs
(ideal, assume duty factor 100% and ε=100%)

- Belle (II) / BaBar
  σ(e+e–→c$\bar{c}$X)≃1.2 nb (√s≃10.6 GeV)
  Belle I 1–2 fb^{-1}/day → 4.4–8.8 x 10^8 $c\bar{c}$ per year
  Belle II 40 fb^{-1}/day → 17.5 x 10^9 $c\bar{c}$ per year
- BESIII
  Example: on J/ψ resonance, σ(e+e– →J/ψ)=2450 nb
  BESII, Phys. Lett. B355(1995)374
  $\mathcal{L}$=6.5 x 10^{32} cm^{-2} s^{-1}
  → 50 x 10^9 per year*
- PANDA
  Example: on J/ψ resonance, σ($p\bar{p}$ →J/ψ)=5250 nb
  from detailed balance (M. Galuska, S.L. et al., arXiv:1311.7597)
  HESR high resolution $\mathcal{L}$=2 x 10^{31} cm^{-2} s^{-1} → 3.3 x 10^9 per year*
  HESR high luminosity $\mathcal{L}$=2 x 10^{32} cm^{-2} s^{-1} → 33 x 10^9 per year*

*(if all year on-resonance)

X(3872)

X(3872)

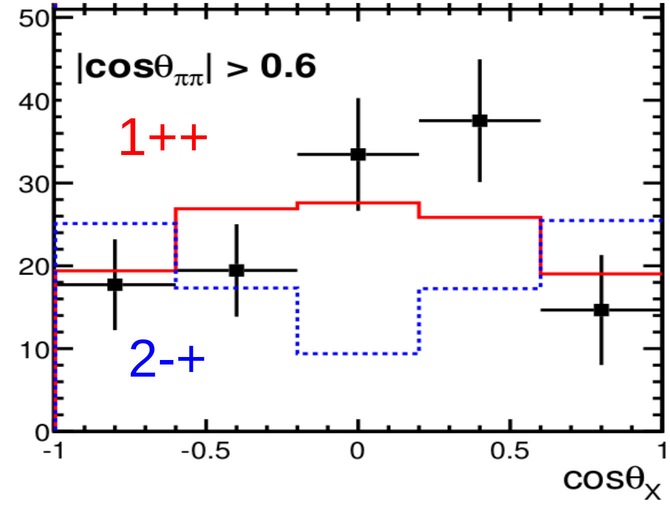


Belle
B decays
Candidates / 5 MeV
m(J/ψπ+π−) / MeV
BaBar
B decays
Candidates / 5 MeV
m(J/ψπ+π−) / GeV
LHCb
B decays
ψ´
X(3872)
Candidates / 2 MeV
m(J/ψπ+π−) / MeV
inclusive
CDF-II
ψ´
X(3872)
Candidates / 5 MeV
m(J/ψπ+π−) / GeV
X(3872)
ψ´
D0
inclusive
Candidates / 10 MeV
m(J/ψπ+π−)-m(μ+μ−) / GeV
ψ´
CMS
inclusive
X(3872)
Candidates / 4 MeV
m(J/ψπ+π−) / GeV

What do we know about the X(3872) ?

- Observed by 7 experiments
- Observed in 5 decay channels
- Quantum numbers are $J^{PC}=1^{++}$
  charmonium potential model: χ_{c1}'
  Barnes, Godfrey, Swanson,
  , Phys. Rev. D72(2005)054026
  $\rightarrow$ predicted mass ≥50 MeV higher

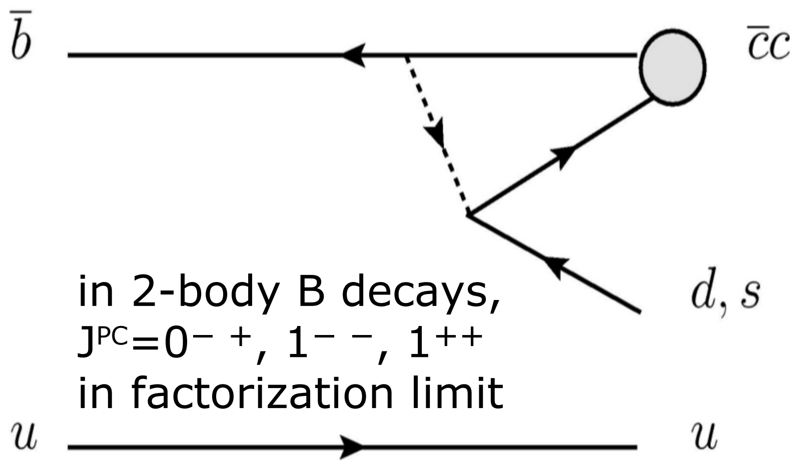
LHCb, Phys. Rev. Lett. 110(2013)222001



- can not be produced in $e+e- \rightarrow \gamma* \rightarrow X(3872)$
  ($e+e- \rightarrow \gamma*\gamma* \rightarrow X(3872)$ is possible, but suppressed)

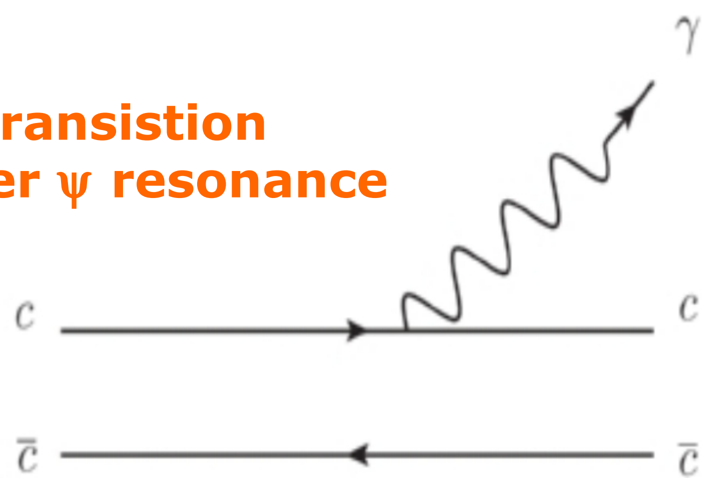
Mechanisms to produce $J^{PC}=1^{++}$

Belle/BaBar: B Meson Decays

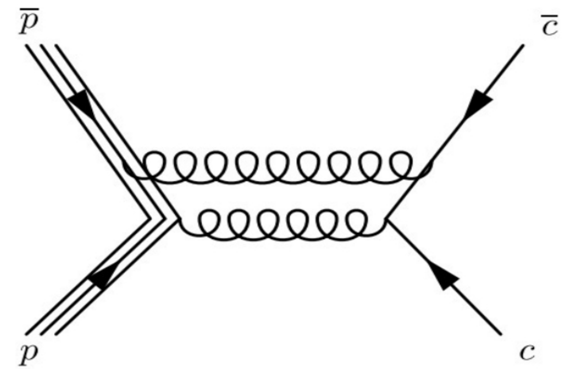


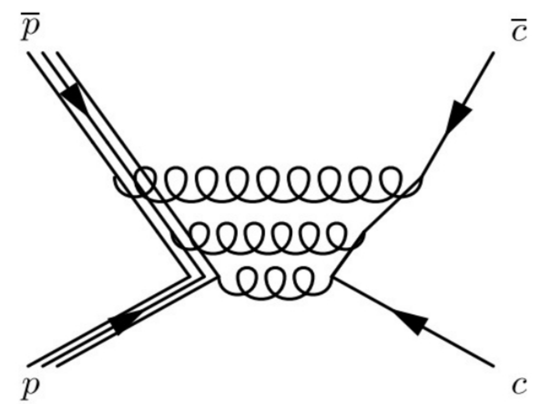
in 2-body B decays,
$J^{PC}=0^{-+}, 1^{--}, 1^{++}$
in factorization limit

BESIII:
radiative transistion
from higher ψ resonance



PANDA: $p\bar{p}$





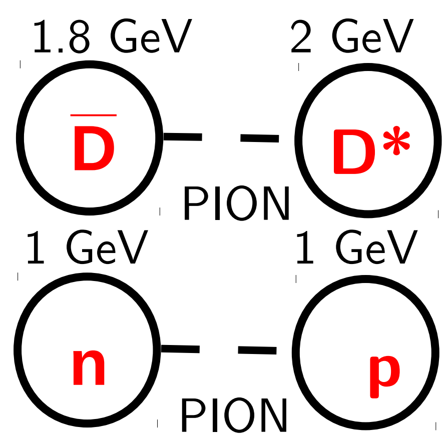
Precise Measurement of Mass of X(3872)

Experiment	Mass of X(3872)
CDF2	3871.61±0.16±0.19 MeV
BABAR (B^+)	3871.4±0.6±0.1 MeV
BABAR (B^0)	3868.7±1.5±0.4 MeV
D0	3871.8±3.1±3.0 MeV
Belle	3871.84±0.27±0.19 MeV
LHCb	3871.95±0.48±0.12 MeV
World Average	3871.68±0.17 MeV

Belle, Phys. Rev. Lett.91(2003)262001
CDF-II, Phys. Rev. Lett.93(2004)072001
D0, Phys. Rev. Lett.93(2004)162002
BaBar, Phys. Rev. D71(2005)071103
LHCb, Eur. Phys. J. C72(2012)1972
CMS, arXiv:1302.3968[hep-ex]

- threshold
  $m(D^0)+m(D^{*0})$=3871.84±0.28 MeV
  „binding energy" −0.16±0.33 MeV
- Is the X(3872) a $D^0\overline{D}^{*0}$ molecule?

Intriguing Analogon



What important knowledge is missing?
→ Width of X(3872)

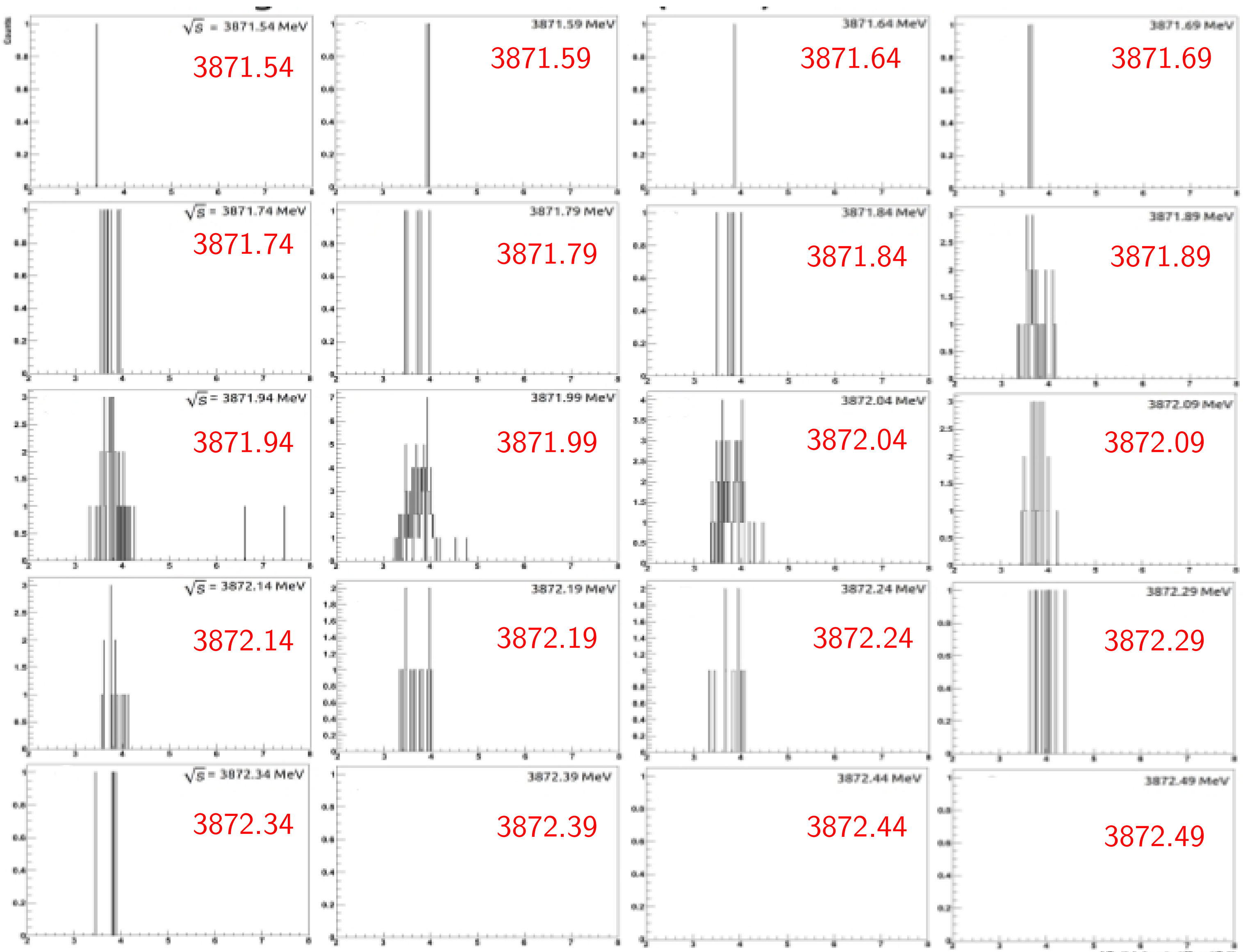
upper limit on width (Belle I),
$\Gamma < 1.2$ MeV

for pure χ_{c1}' charmonium state,
prediction $\Gamma = 40$ keV
G. Y. Chen, J. P. Ma, arXiv:0802.2982[hep-ph], Phys. Rev. D77(2008]097501.

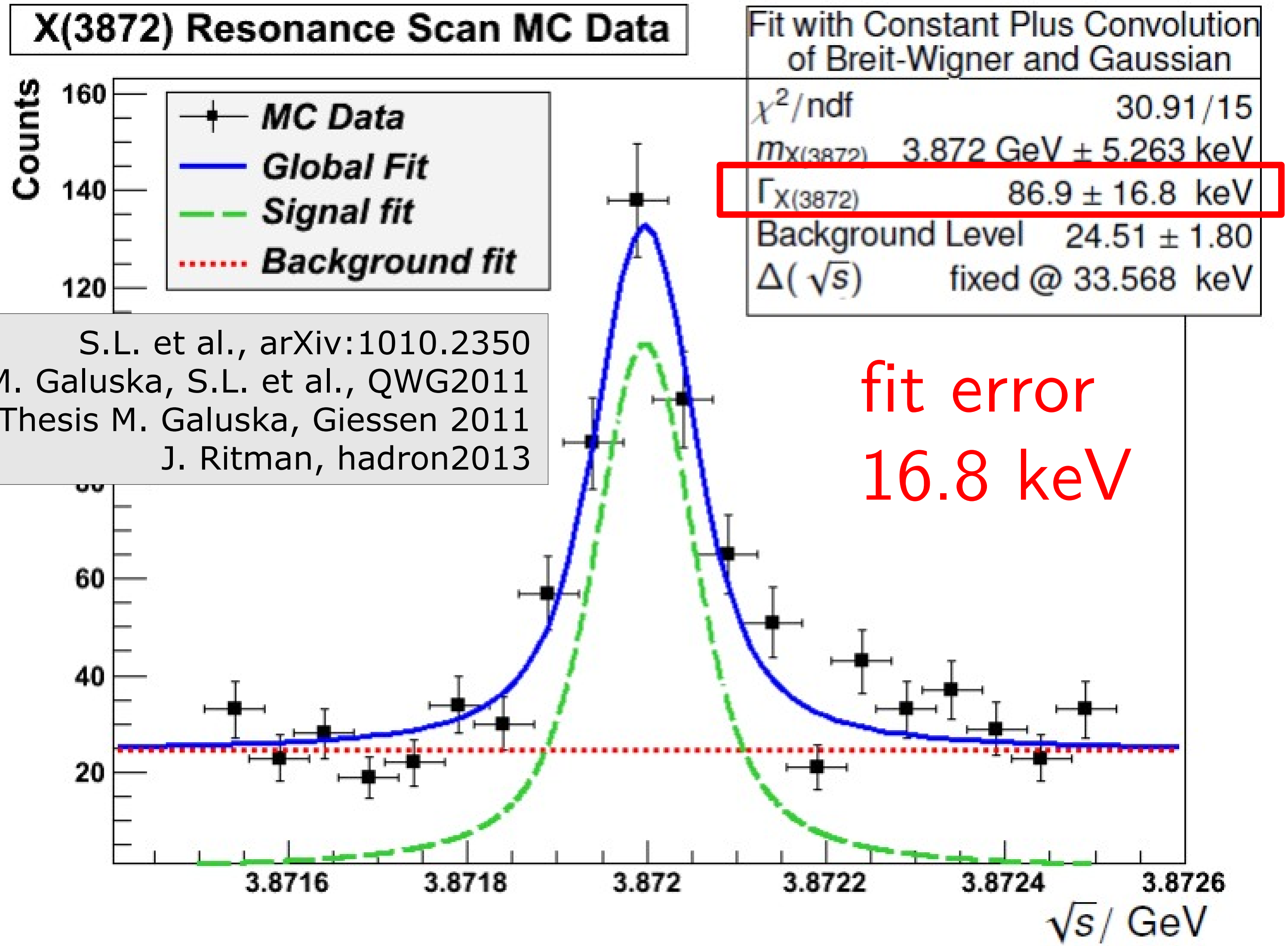
if molecule
- must be larger than width of D*
  Γ > 82.3±1.2±1.4 keV
  E. Braaten, arXiv:0711.1854 [hep-ph], Phys. Rev. D77(2008)034019.
- long-range molecular components in the wavefunction?

→ measure the width of the X(3872)
in the sub-MeV regime

Resonance Scan of X(3872) → J/ψ π+π− at PANDA (MC)



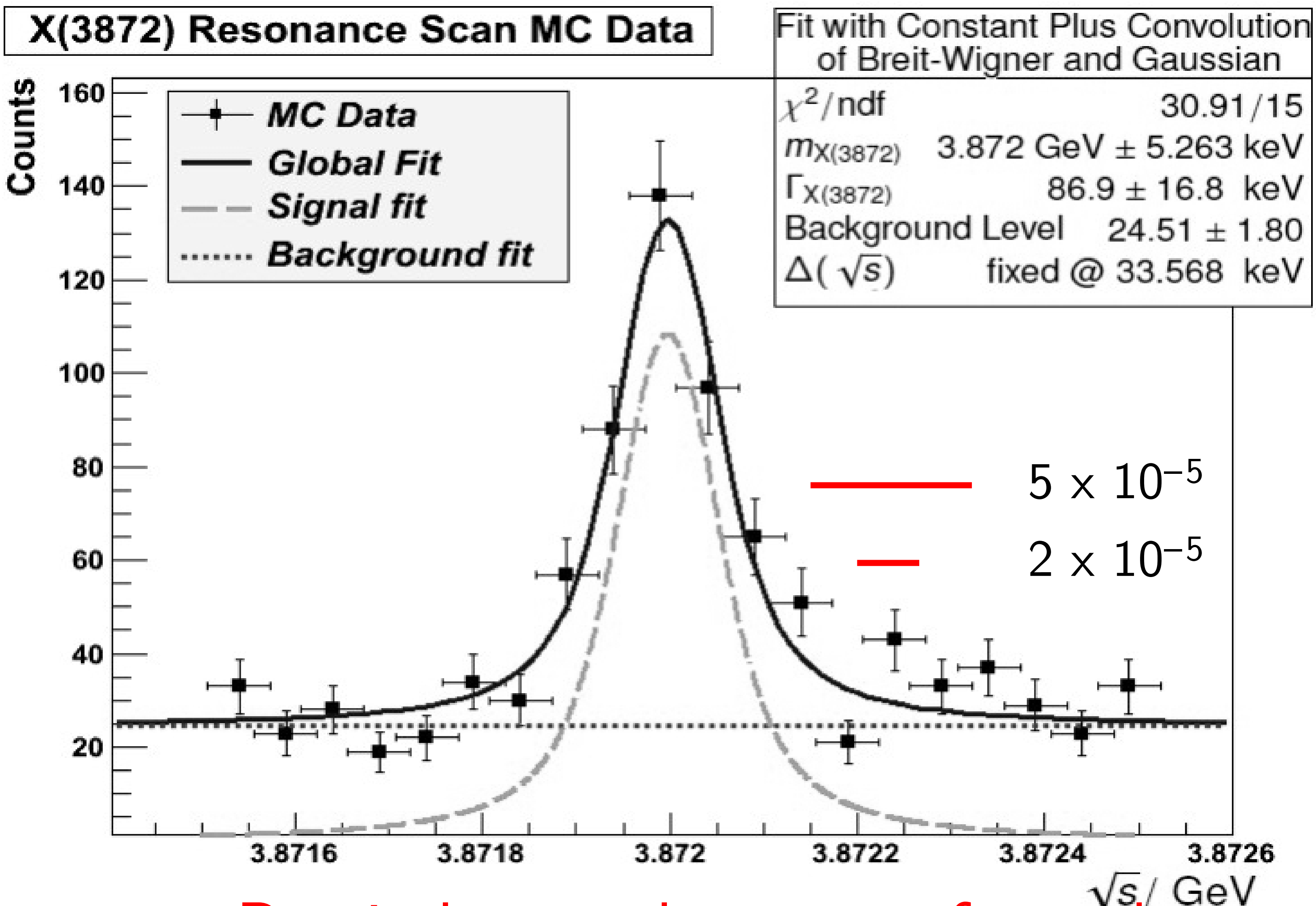
S.L. et al., arXiv:1010.2350, M. Galuska, S.L. et al., QWG2011, Master Thesis M. Galuska, Giessen 2011



S.L. et al., arXiv:1010.2350
M. Galuska, S.L. et al., QWG2011
Master Thesis M. Galuska, Giessen 2011
J. Ritman, hadron2013

fit error
16.8 keV

Natural width of 100 keV can be reproduced
(within the error bars)



Reminder: study was performed using $\Delta p/p = 2 \times 10^{-5}$

X(3872) – PANDA vs. Belle II vs. BESIII

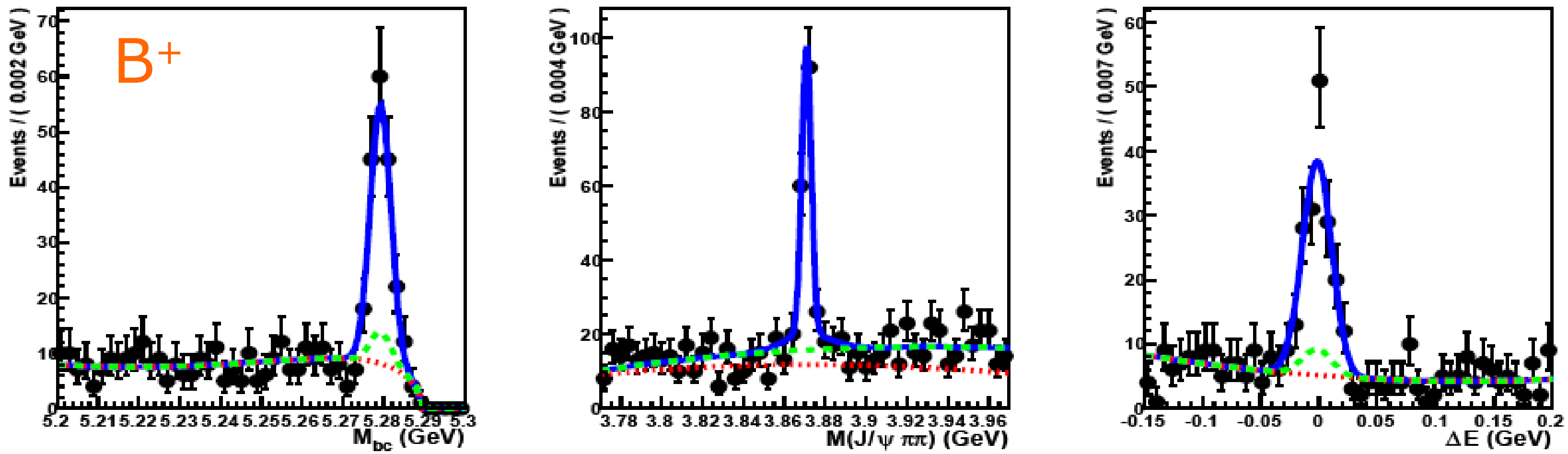
- Consider only [$J/\psi\pi+\underline{\pi}-$] decay mode
- PANDA, assume $\sigma(pp \to X(3872))=50$ nb
  statistics ~130 (1300) per day on peak for $\mathcal{L}=2 \times 10^{31}$ (10^{32}) $cm^{-2}\,s^{-1}$
  efficiency ~50% (4 charged, exclusive)
  high boost $\beta_{cms}=0.89$ (fixed target) $\to \beta\gamma=1.95$
  mass resolution ~50-100 MeV (unfitted)
- Belle II
  statistics ≃1500 by 2020
  effiency 15-20%
  small boost $\beta\gamma=0.43$ (Belle), $\beta\gamma=0.28$ (Belle II)
  mass resolution ~10-20 MeV (unfitted)
- BESIII
  $e+e- \to Y(4260) \to \gamma X(3872)$ BESIII, Phys. Rev. Lett. 112(2014)092001
  ≃1200 Y(4260) per day ($\sigma\simeq60$ pb, integrated luminosity ≃20 pb^{-1}/day)
  but branching fraction small, only ≃0.5% (≃20 events in ~4 weeks)
  rare

X(3872) Width Measurement at Belle I

$M_{bc} \equiv \sqrt{(E_{beam}^{cms})^2 - (p_B^{cms})^2}$

$X(3872) \rightarrow J/\psi\, \pi^+ \pi^-$

$\Delta E \equiv E_B^{cms} - E_{beam}^{cms}$



M_{BC} /GeV $\quad$ $M(J/\psi\, \pi^+ \pi^-)$/GeV $\quad$ ΔE/GeV

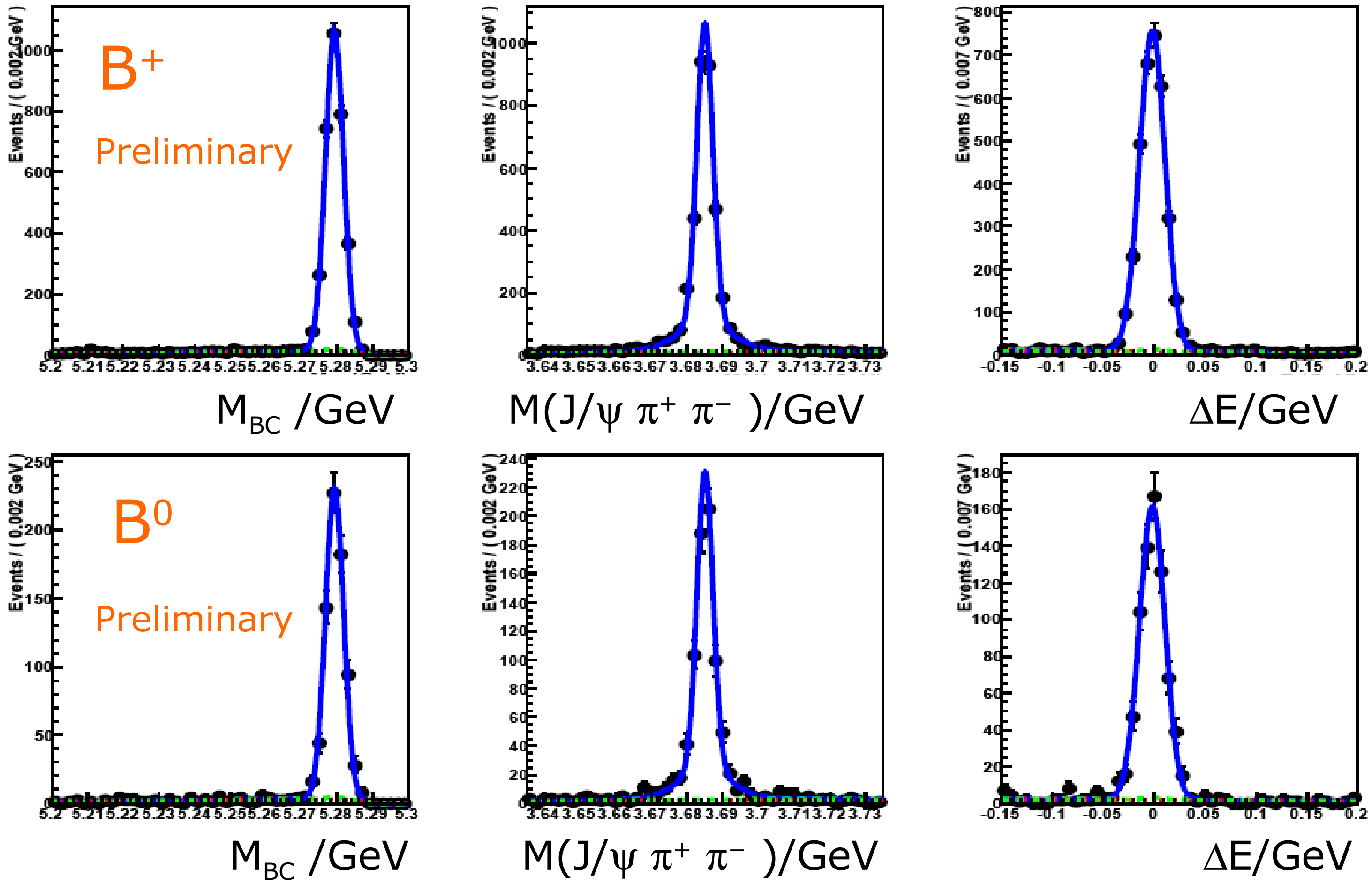
- 3-dim fit → kinematical over-constraint provides access to observables smaller than detector resolution
- upper limit on width $\Gamma_{X(3872)} < 1.2$ MeV (90% C.L.)
- S/B$\simeq$10/1

Belle, Phys. Rev. D84(2011)052004
S.L., hadron2011

Reference Analysis: $B \to K\psi'$, $\psi' \to J/\psi\ \pi^+\pi^-$

$$M_{\rm bc} \equiv \sqrt{(E_{\rm beam}^{\rm cms})^2 - (p_B^{\rm cms})^2}$$

$$\Delta E \equiv E_B^{\rm cms} - E_{\rm beam}^{\rm cms}$$



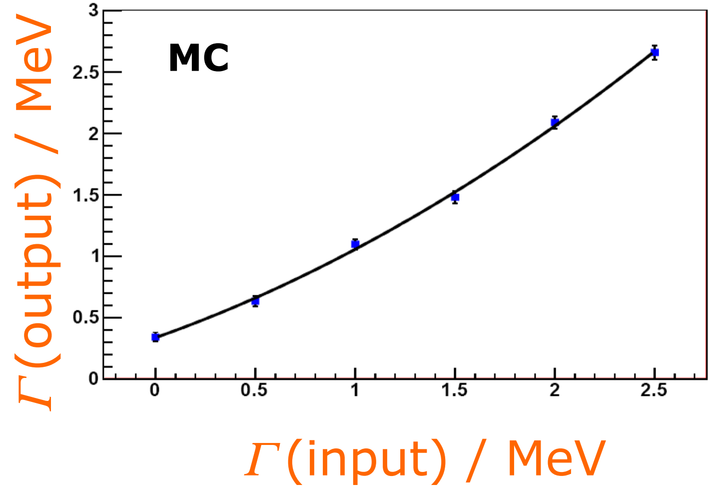
factor ~10 more statistics than X(3872) → use as reference signal

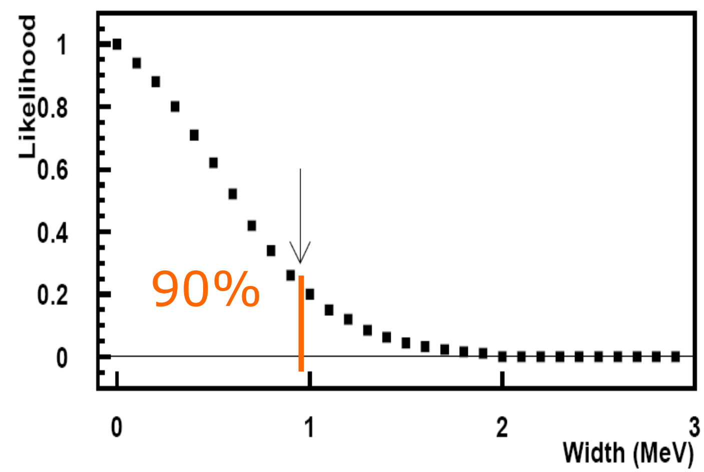
→ fix resolution parameters

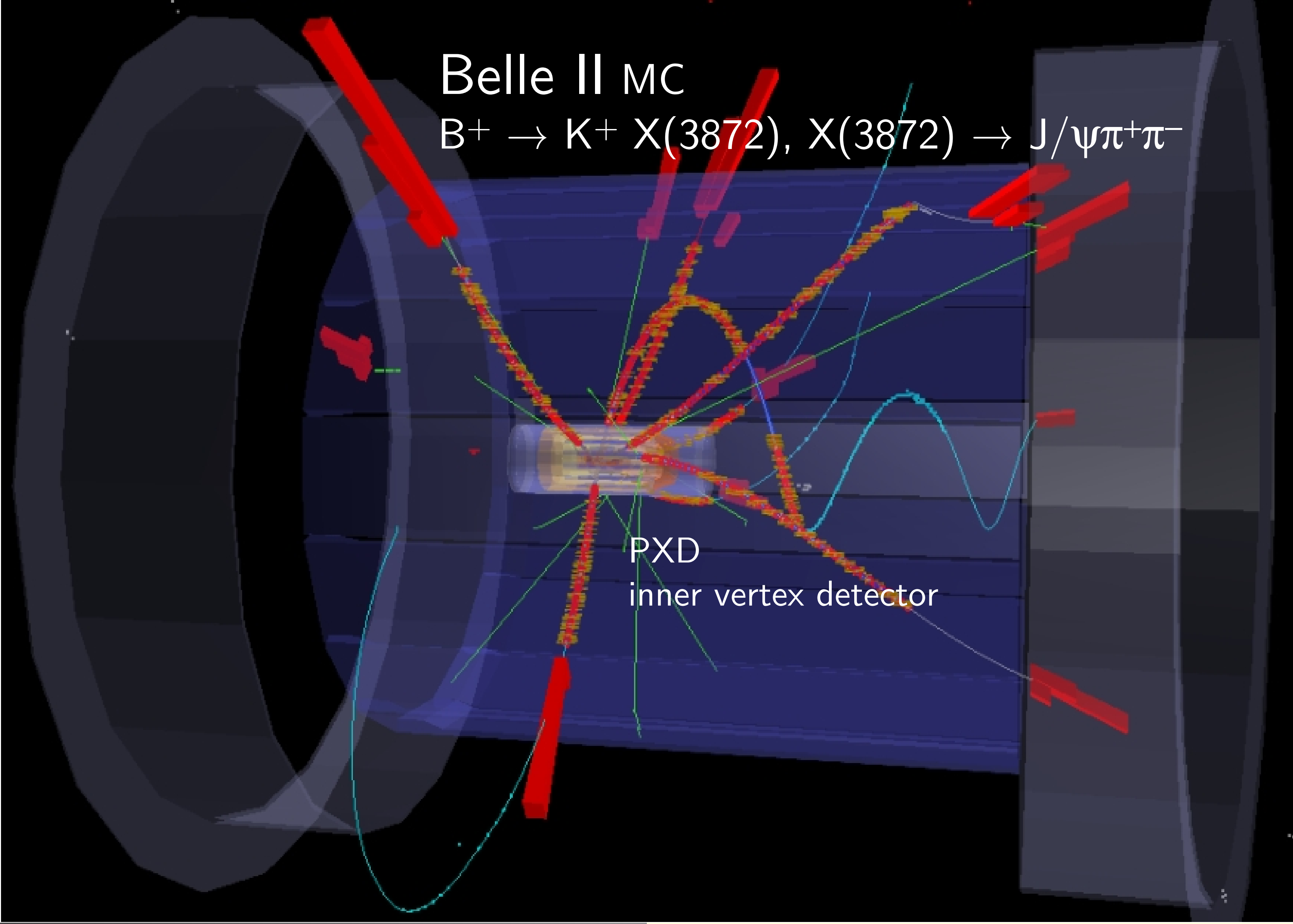
→ fix absolute mass scale (MC/data shift +0.92±0.06 MeV)

Measurement of width of X(3872)

- Correlation function from MC
  Γ(output) = f(Γ(input))
- 3-dim fits validated with ψ' width
  $\Gamma_{\psi'}$=0.52±0.11 MeV
  (PDG 0.304±0.009 MeV)
  → bias 0.23±0.11 MeV
- procedure for upper limit:
  width in 3-dim fit fixed
  n_{signal} and n_{BG} floating
  → calculate likelihood
- $\Gamma_{X(3872)}$ < 0.95 MeV + bias
  (0.95 MeV + bias) = 1.2 MeV



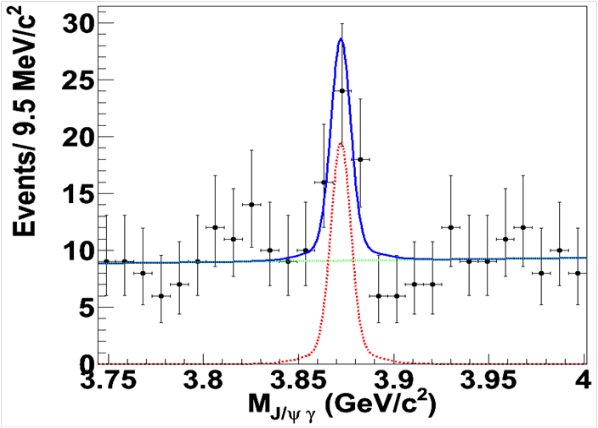




Belle II MC
$B^+ \to K^+ X(3872)$, $X(3872) \to J/\psi\pi^+\pi^-$
PXD
inner vertex detector

X(3872) at Belle II

- yield of X(3872) $\to$ J/ψπ+π– in 2020
  will be about Belle I yield of ψ' $\to$ J/ψπ+π–
- if $\Gamma_{X(3872)} > 0.23$ MeV (bias)
  the width of the X(3872) can be measured
  with a systematic error of ± 0.11 MeV
- width measurement in X(3872) $\to$ J/ψγ
  expected yield N$\simeq$350 in 2020
  scaled from Belle, Phys. Rev. Lett. 107(2011)091803
  (factor ≥2 more than X(3872) $\to$ J/ψπ+π– at Belle I)
  → monoenergetic photon
  provides 4th constraint
  (ΔE/E~2%)
  $\to$ systematic error on width
  may be ≤110 keV
  (but 10 keV may be impossible)

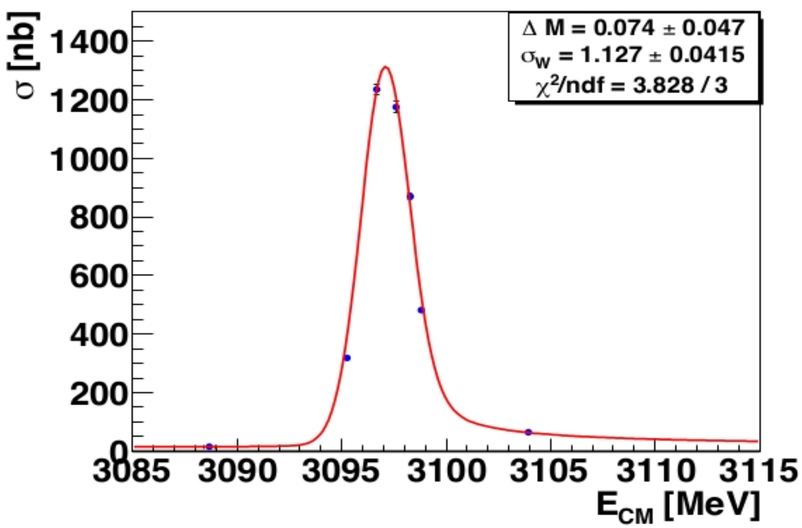


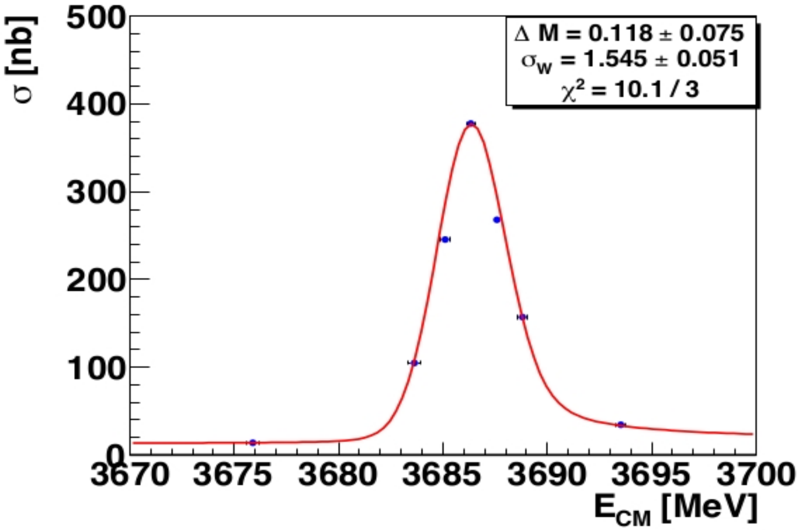
J/ψ and ψ' resonance scan in e+e− at BESIII

beam energy spread

Scan	ΔM (MeV /c²)	δ_w (MeV)
J/ψ	$0.074 \pm 0.047 \pm 0.043$	$1.127 \pm 0.042 \pm 0.050$
ψ'	$0.118 \pm 0.076 \pm 0.021$	$1.545 \pm 0.051 \pm 0.069$

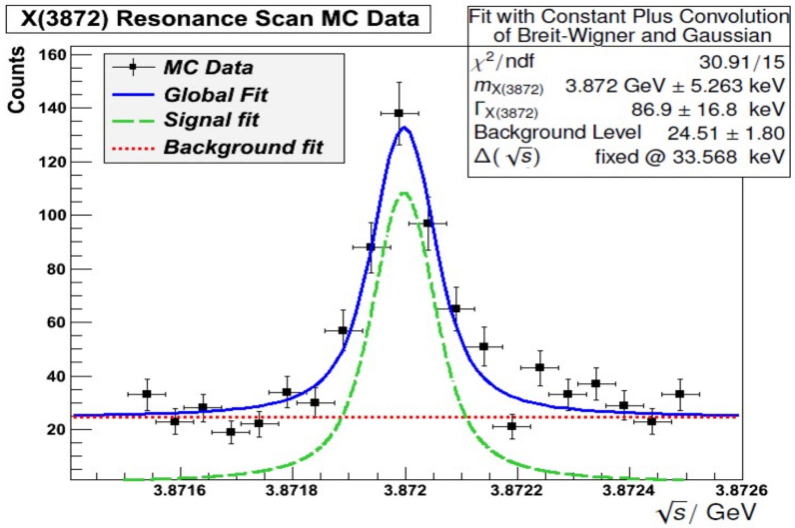
larger than upper limit on width of X(3872) $\Gamma < 1.2$ MeV (Belle)





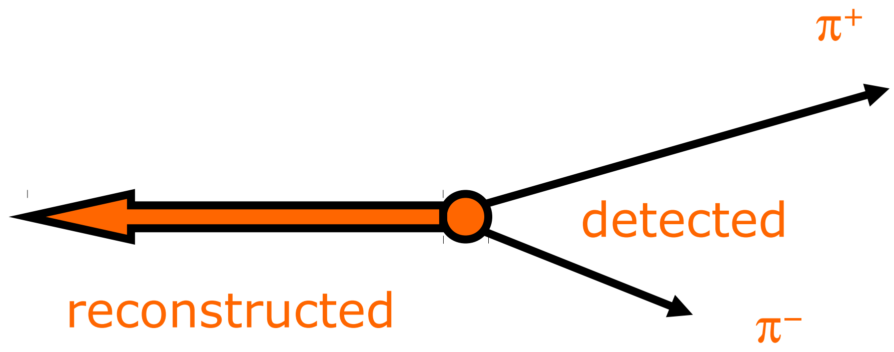
Tao Luo, TAU2014

X(3872) - What about signal/background?



- X(3872) at Belle I:
  S/B=10/1
- X(3872) at PANDA:
  S/B=7/1
  surprisingly good.
  where is the background?
  $\rightarrow J/\psi \rightarrow \mu+\mu-$, e+e– "tagging"
  reduces hadronic background by factor $\geq 10^3$
- reminder: resonance scan is also special situation:
  → we know where it is!
- what if we search for a new state ?
  → scanning a few GeV mass range with 10-100 keV steps
  impossible.
  solution: "recoil mass"

PANDA: search for a new state h_c'



PRODUCTION, not FORMATION

p_{beam} = 15 GeV/c

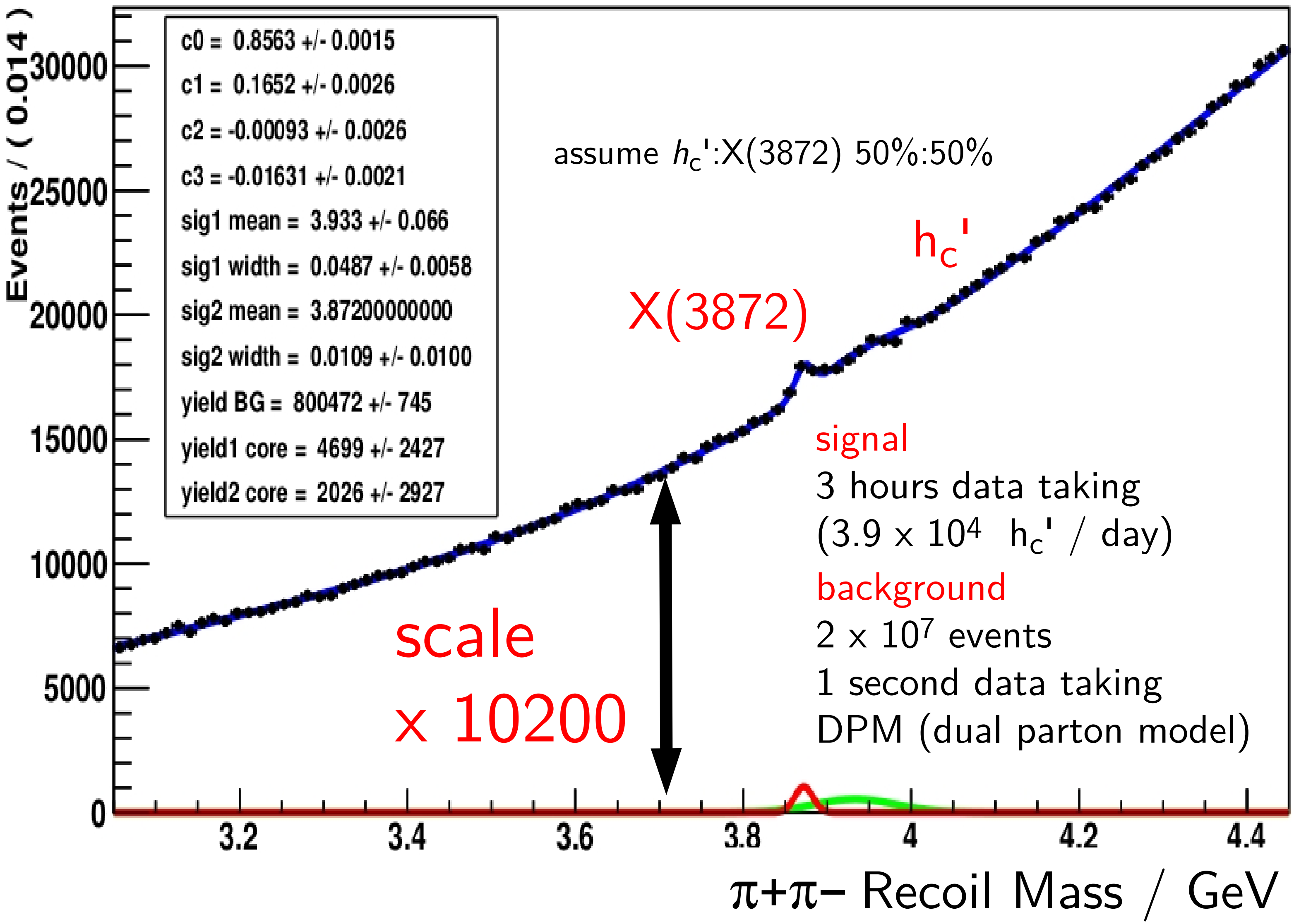
$p\bar{p} \rightarrow h_c' \pi^+ \pi^-$

$h_c' \rightarrow D^0 \overline{D}^{0*}$

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

$\overline{D}^{0*} \rightarrow$ anything

X(3872) as reference



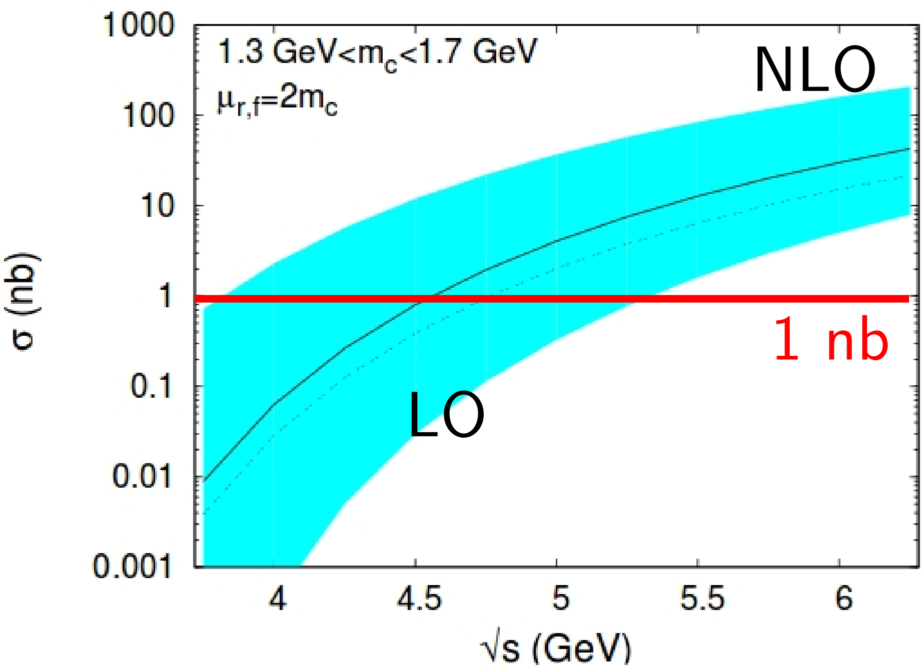
M. Galuska, S. Reiter, E. Prencipe, S. Spataro, S.L., arXiv:1311.7597[hep-ex]
Bachelor Thesis S. Reiter, Giessen 2013

Open Charm, electroweak physics

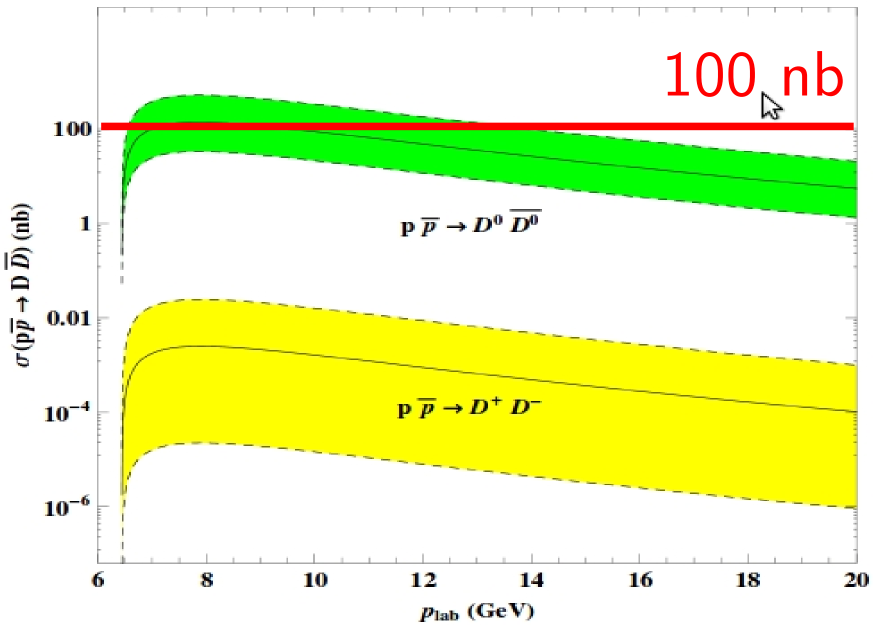
CP violation in D Mesons

a “benchmark”

Open charm cross section at PANDA (Theory)



$\sigma(p\bar{p} \to c\bar{c})$
E. Braaten, P. Artoisenet
arXiv:0803.2573[hep-ph]
Phys. Rev. D79(2009)114005



$\sigma(p\bar{p} \to DD)$
A. Khodjamirian, C. Klein,
Th. Mannel, Y.M. Wang
arXiv:1111.3798[hep-ph]
Eur. Phys. J. A48(2012)31

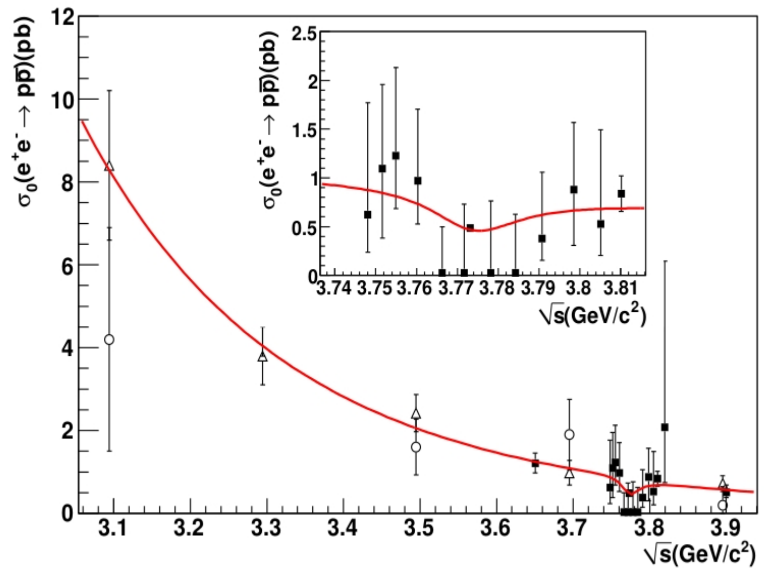
Open charm cross section at PANDA (Experiment)

BESIII, Phys.Lett. B735(2014)101, arXiv:1403.6011[hep-ex]

$\psi(3770) \to D^0D^0$ (50%)

$\psi(3770) \to D^+D^-$ (50%)

Detailed balance:
determine
$\sigma(pp \to \psi(3770))$
at PANDA
from
$\sigma(\psi(3770) \to p\bar{p})$
at BESIII



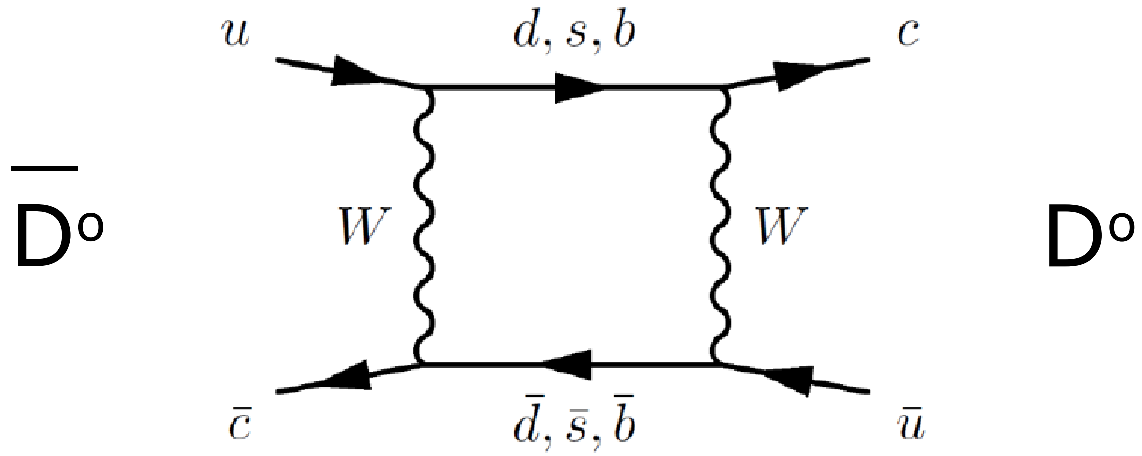
QM interference
of signal and background
2 solutions:
(9.8+11.8−3.9) nb
(425.6+42.9−43.7) nb

Time-dependant CP violation in D^0 mesons

$$A_\Gamma = \frac{\tau(\overline{D}^0 \to K^-K^+) - \tau(D^0 \to K^+K^-)}{\tau(\overline{D}^0 \to K^-K^+) + \tau(D^0 \to K^+K^-)}$$

Very clean probe to beyond SM physics

No top quark in loop



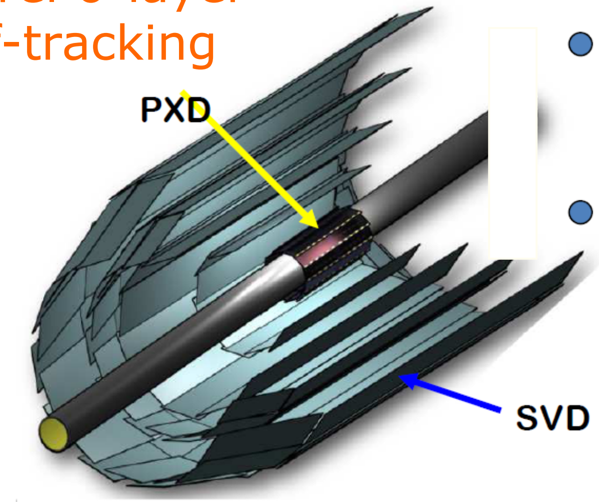
Comparison of VXD Systems

Belle II

PXD (all pixel)
- r=1.4 cm
- (50 x 50 μm², d=75 μm)
- r=2.2 cm
- (50 x 75 μm², d=75 μm)

SVD (all strip)
- r=3.8 cm
- r=8.0 cm
- r=11.5 cm
- r=14.0 cm

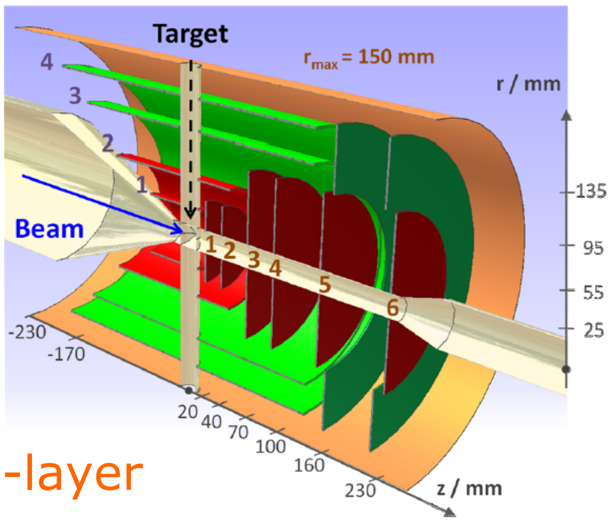
barrel 6-layer
self-tracking



Panda

MVD barrel
- r=2.5 cm (pixel,
- 100 x 100 μm², d=300 μm)
- r=5.0 cm (pixel,
- 100 x 100 μm², d=300 μm)

MVD disk
- z= 2.0 cm (pixel)
- z= 4.0 cm (pixel)
- z= 7.0 cm (pixel)
- z=10.0 cm (pixel)
- z=16.0 cm (pixel+strip)
- z=23.0 cm (pixel+strip)

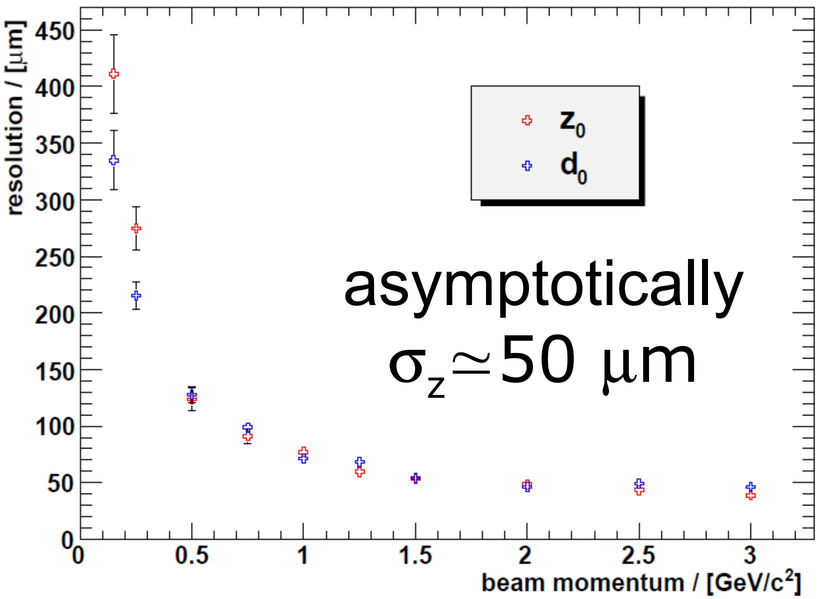


barrel 4-layer

Comparison of vertex resolutions

PANDA MVD (MC)

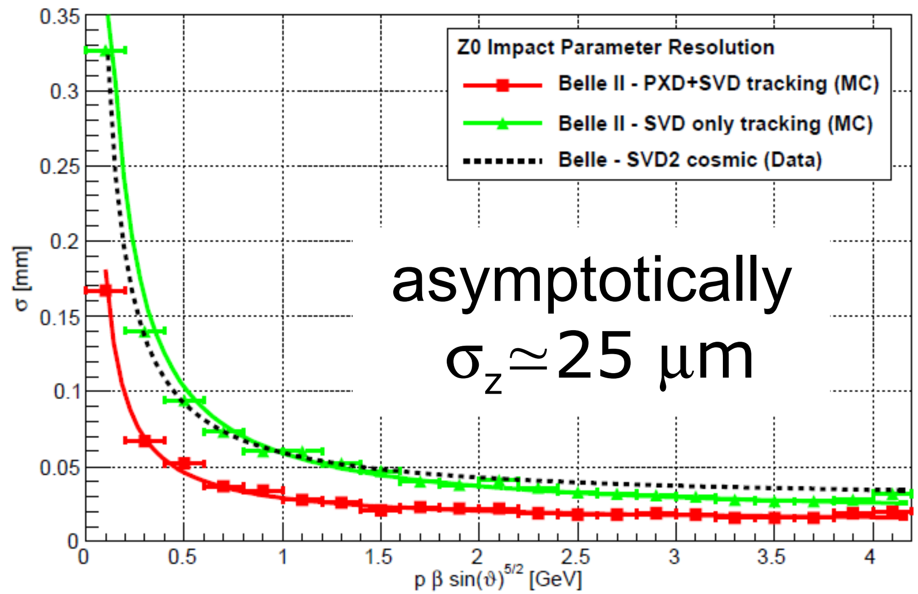
$\pi^{\pm}$



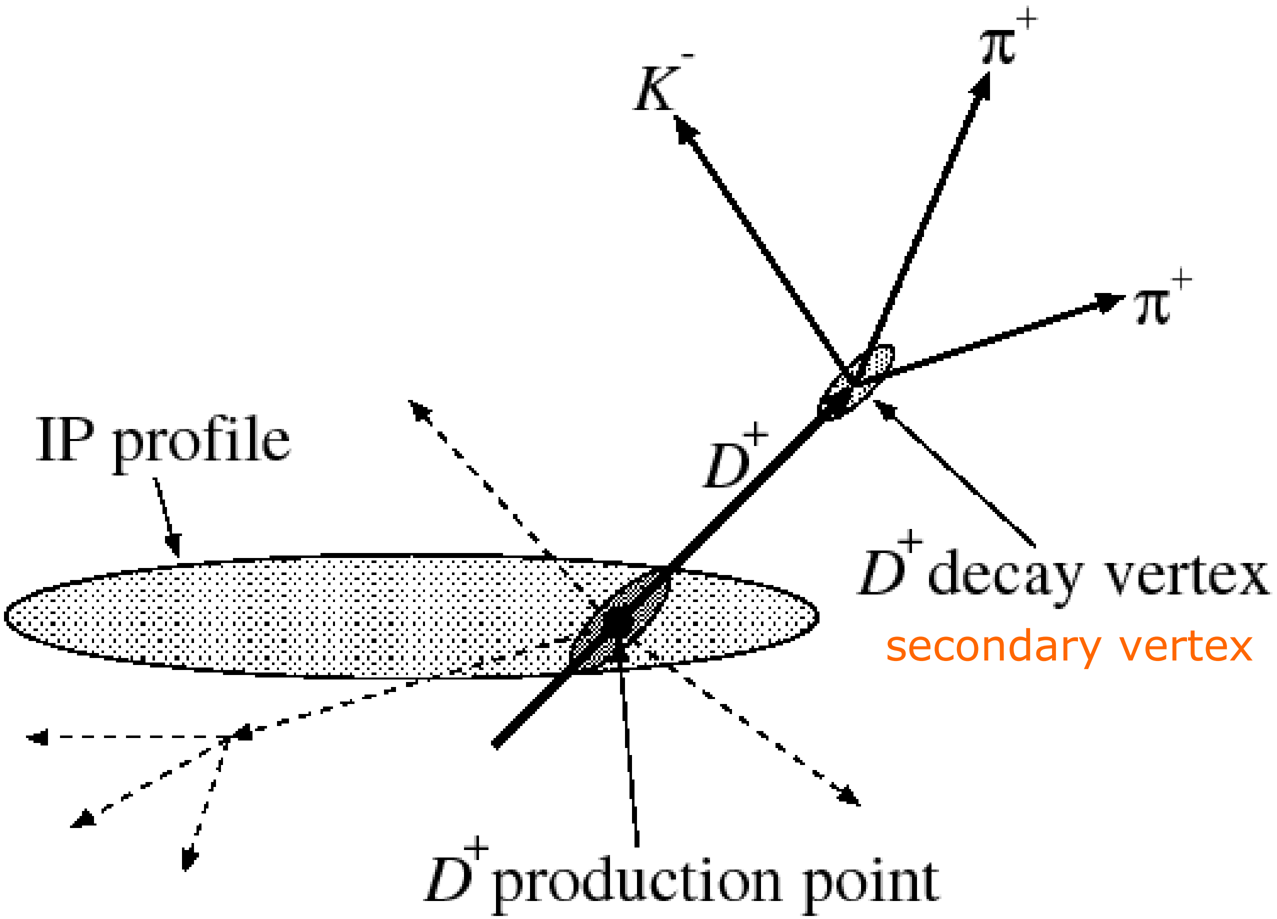
Ph. D. Thesis Rene Jäckel (Dresden)

Belle II PXD+SVD (MC)

$\mu^{\pm}$



Open Charm Vertex Reconstruction



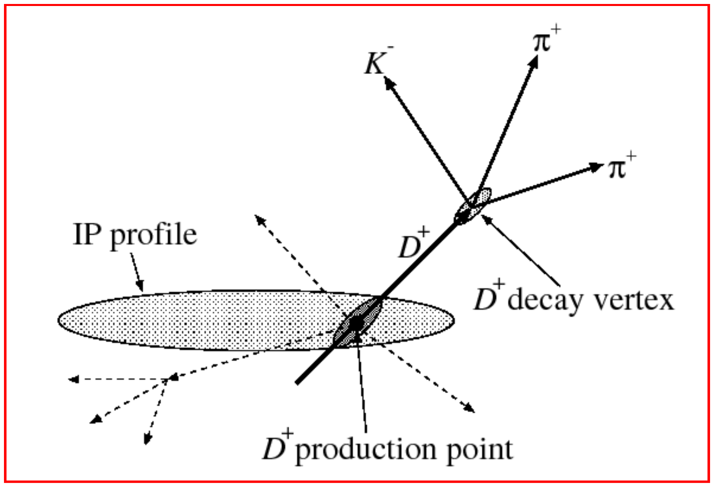
secondary vertex

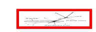
primary vertex

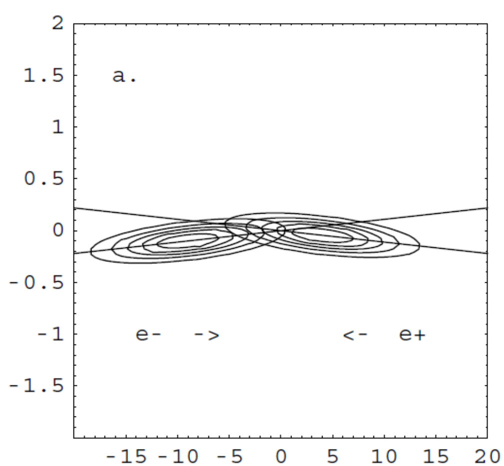
Belle I (achieved)	PANDA (MC)
• Decay vertex double Gaussian - 67%*(38±3) µm - 33%*(104±8) µm average ~60 µm (in D meson flight direction)	• Decay vertex single Gaussian 88.4-94.9 µm (z only) (MVD TDR)
• Production point single Gaussian 14.8±0.3 µm much better than decay vertex	• Production point single Gaussian 197.4 µm (Ph. D. Rene Jäckel, 2009) w/ pellet (1.6 mm extended target region)

IP Profile for Belle and Belle II („nanobeam“)

100µm(H) x 2µm(V) → 10µm(H) x 59nm(V)







Notes:

- time dependant shape (ellipse) increases IP profile
  data from monitoring @ Belle
  100-120 um (x), 5 um (y), 2-3 mm (z)
- alignment procedure still under study for Belle II

$D^0 \to K^+K^-, \pi^+\pi^-$ (update with 976 fb^{-1})

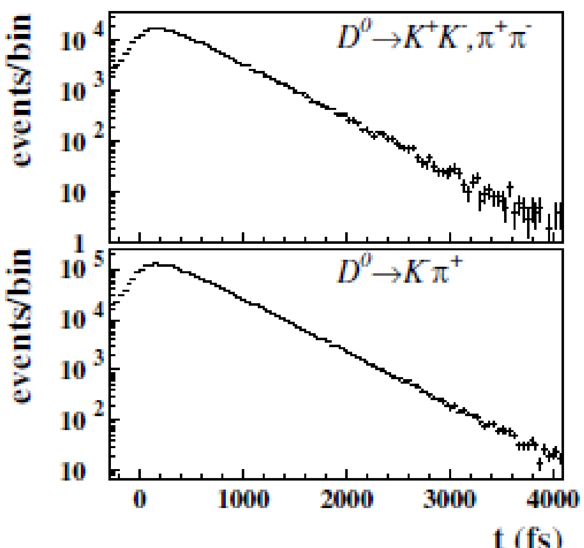
complete Belle data set

Results (preliminary)

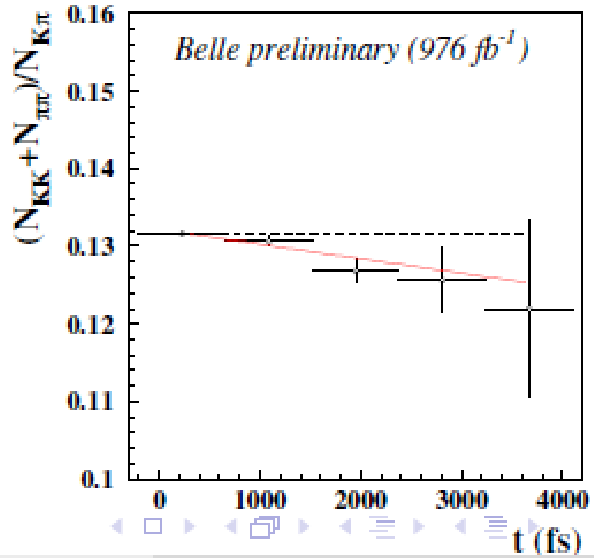
statistics limited

$$A_\Gamma = (-0.03 \pm 0.20 \pm 0.08)\%$$

source	ΔA_Γ (%)
acceptance	0.044
SVD misalignments	0.041
mass window position	0.009
background	0.050
resolution function	0.002
binning	0.010
sum in quadrature	0.08



divide distributions →



Statistics of D^0 mesons

- PANDA
  cross section $\sigma(p\bar{p} \to D^0\bar{D}^0)$≈9.8–425.6 nb (background 8500 nb)
  assume high luminosity mode
  68% reconstruction efficiency (MVD TDR, 4 charged)
  → 2240–93.600 events per day
  (single tag, assume $K\pi$ decay on one side → BR=3.8%)
  x N days for dedicated charm data taking
- Belle I
  reconstruction efficiency ~20% (smaller than Panda)
  - cut $p_{cms}(D^0)$≥2.2 GeV/c
  12.9 x 10^6 $D^0 \to K\pi$ (976 fb^{-1}, CHARM2012)
  → 0.77–31.55 years of PANDA (50% duty cycle)
- Belle II
  132 x 10^6 $D^0 \to K\pi$ by 2020 (integrated)
  in best case 7.7 years of PANDA (assuming higher cross section)
- BESIII $e^+e^- \to \psi(3770) \to D^0\bar{D}^0$,
  $\sigma \simeq$15 nb, BR=50%, 2900 pb^{-1} integrated luminosity recorded
  1.65 x 10^6 $D^0 \to K\pi$ (one side) on tape
  → 18–738 days of PANDA
  (but no boost, no vertex detector)

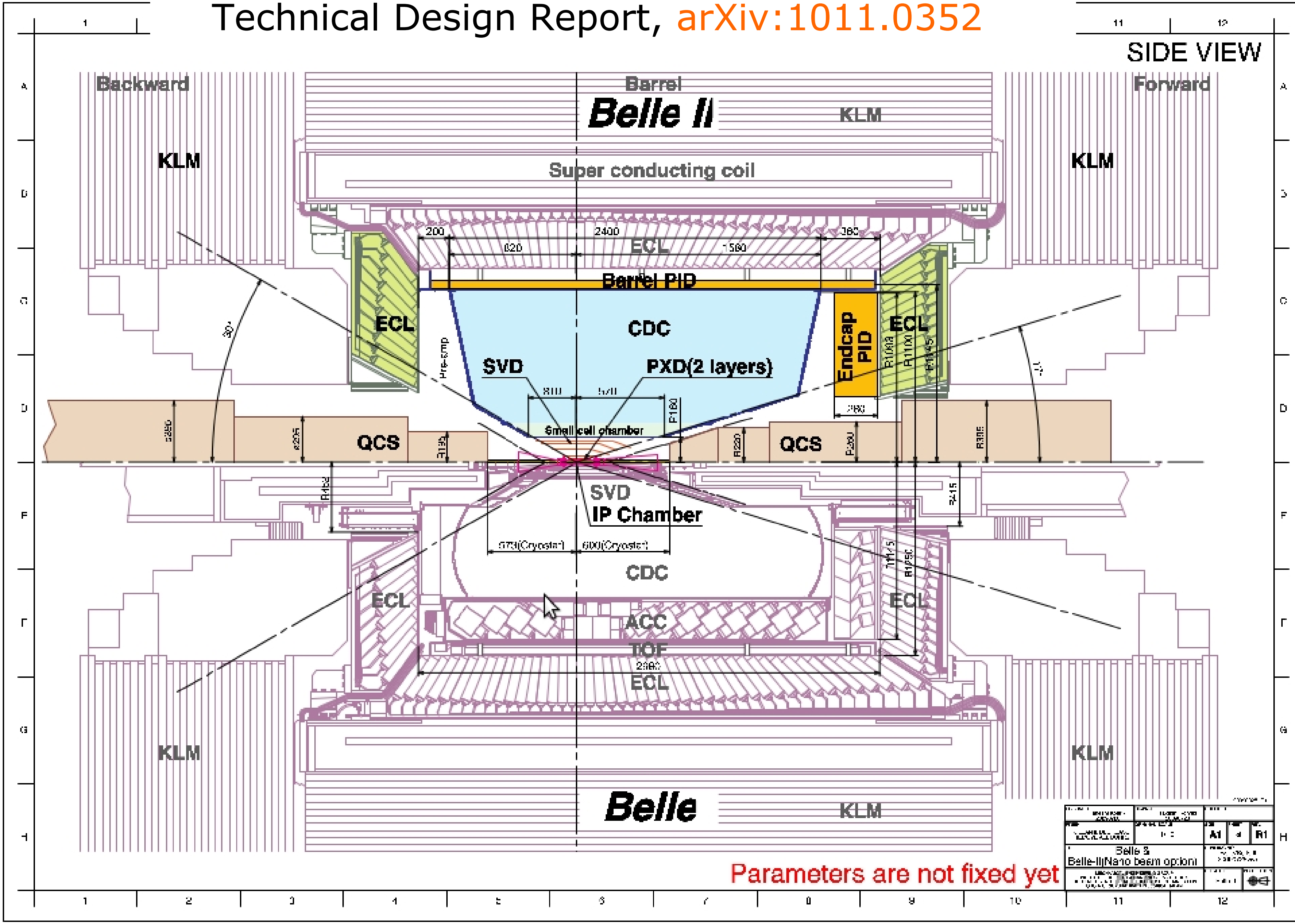
Conclusion

- PANDA, BESIII and Belle II
  all ≥10^9 cc pairs per year
- BESIII presently successfully running
- Belle II extrapolation:
  10 x data set of Belle by 2020
- width measurements:
  for X(3872) resolution of ≥10 keV required
  → for Belle II ±110 keV (syst.) (for masses above 230 keV)
  achieved by 3-dim fit

Acknowledgement:
Thanks to
M. Galuska K. Götzen, W. Gradl, C. Hambrock, F. Nerling, E. Prencipe, M. Wagner

BACKUP

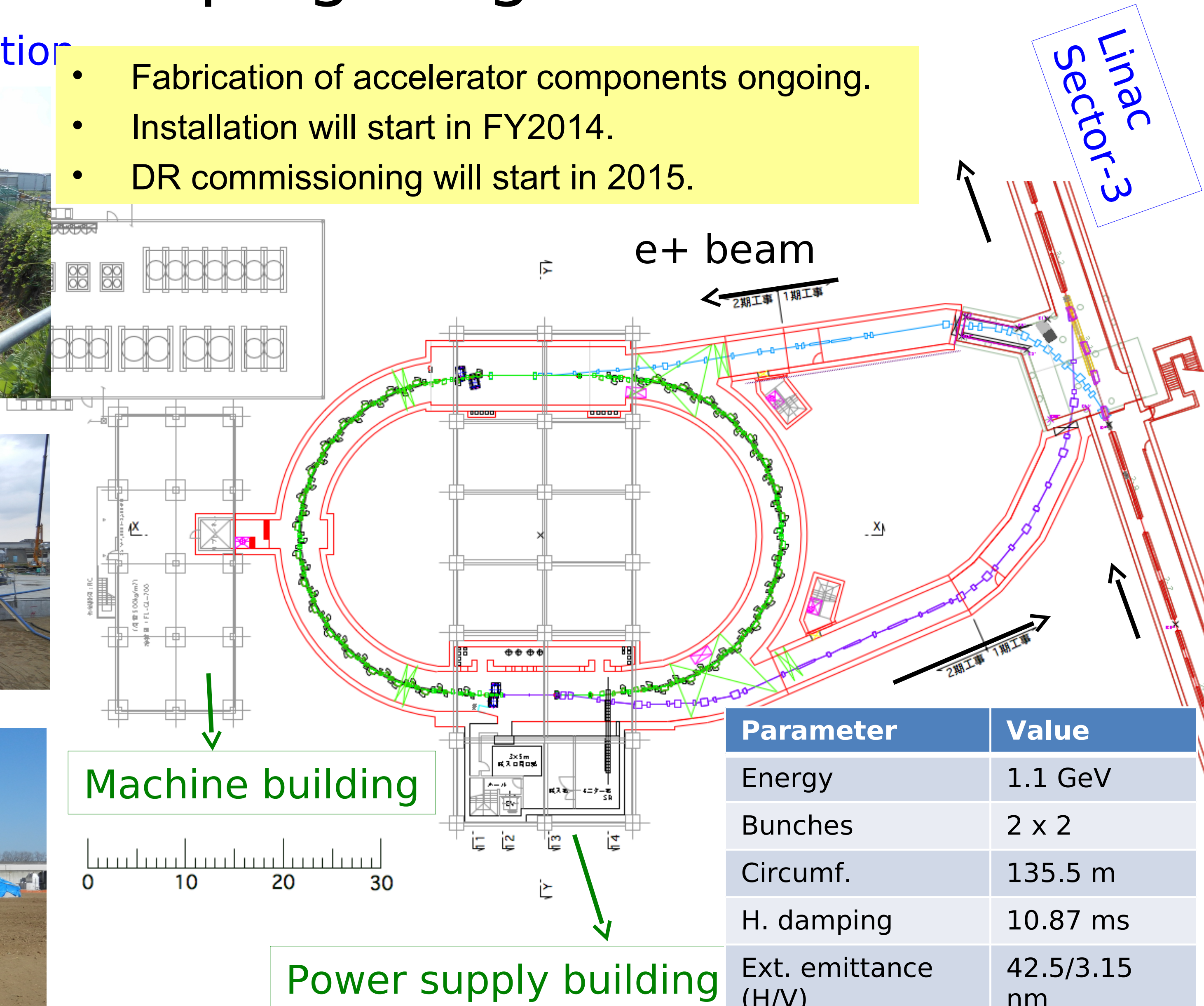
Technical Design Report, arXiv:1011.0352



New Damping Ring for Positrons

DR tunnel construction

- Fabrication of accelerator components ongoing.
- Installation will start in FY2014.
- DR commissioning will start in 2015.



Parameter	Value
Energy	1.1 GeV
Bunches	2 x 2
Circumf.	135.5 m
H. damping	10.87 ms
Ext. emittance (H/V)	42.5/3.15 nm
Max. current	70.8 mA

Luminosity increase

1. beam current

1.64/1.19 A → 3.6/2.6 A for e+ (e–) beam

→ factor 2 increase in luminosity

2. beta function

β_y*

5.9 mm → 0.27 mm

σ_y → 59 nm

''nanobeam''

→ factor 20 increase in luminosity

→ total factor 40 increase in luminosity

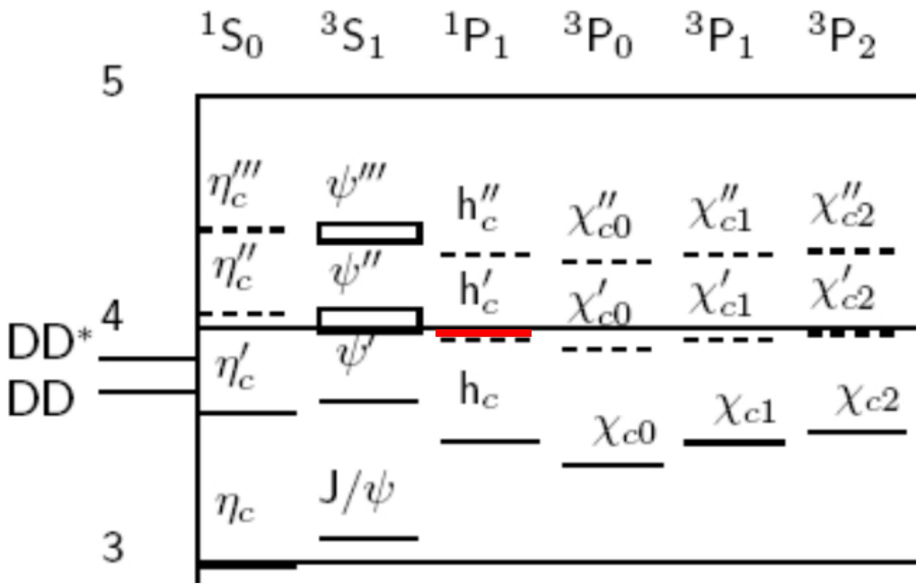
$$\sigma_y(z) \propto \sqrt{\beta_y(z)}$$

$$\beta_y(z) = \beta_y^*(1 + \frac{(z - Z_0)^2}{\beta_y^{*2}})$$

Z_0 is position of minimum beta function („waiste“)

Proposal: search for h_c'(n=2)

- h_c(n=2, $^1P_1$) predicted at 3934-3956 MeV
- Advantage for Panda:
  - even h_c(n=1) not seen in B decays $0-+ \rightarrow 0-+\ 1+-$ (violates factorisation)
  - h_c(n=2) difficult at BESIII e.g. $\psi(4040) \rightarrow \pi^0 h_c'$
    - phasespace small
    - violates isospin (BR small)

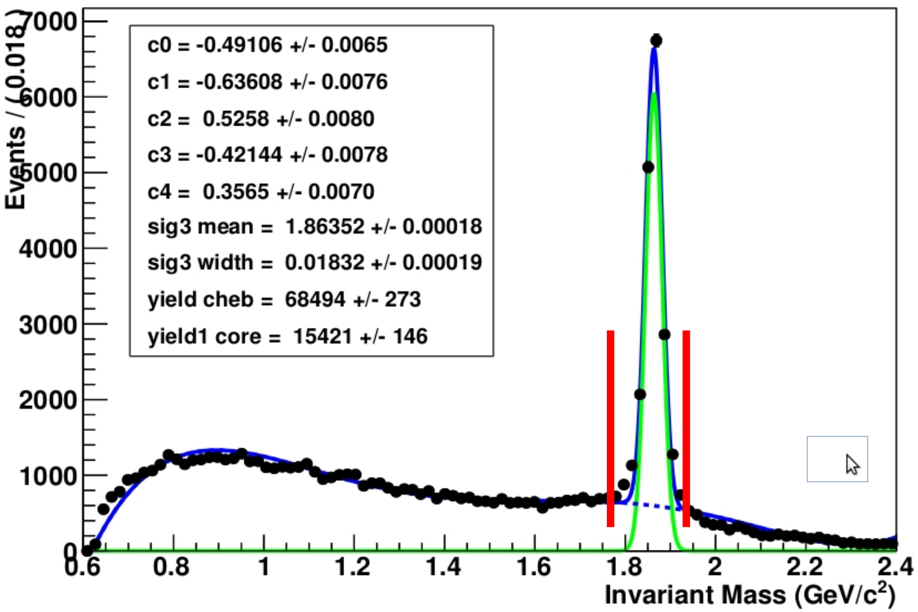


Background rejection for h_c'

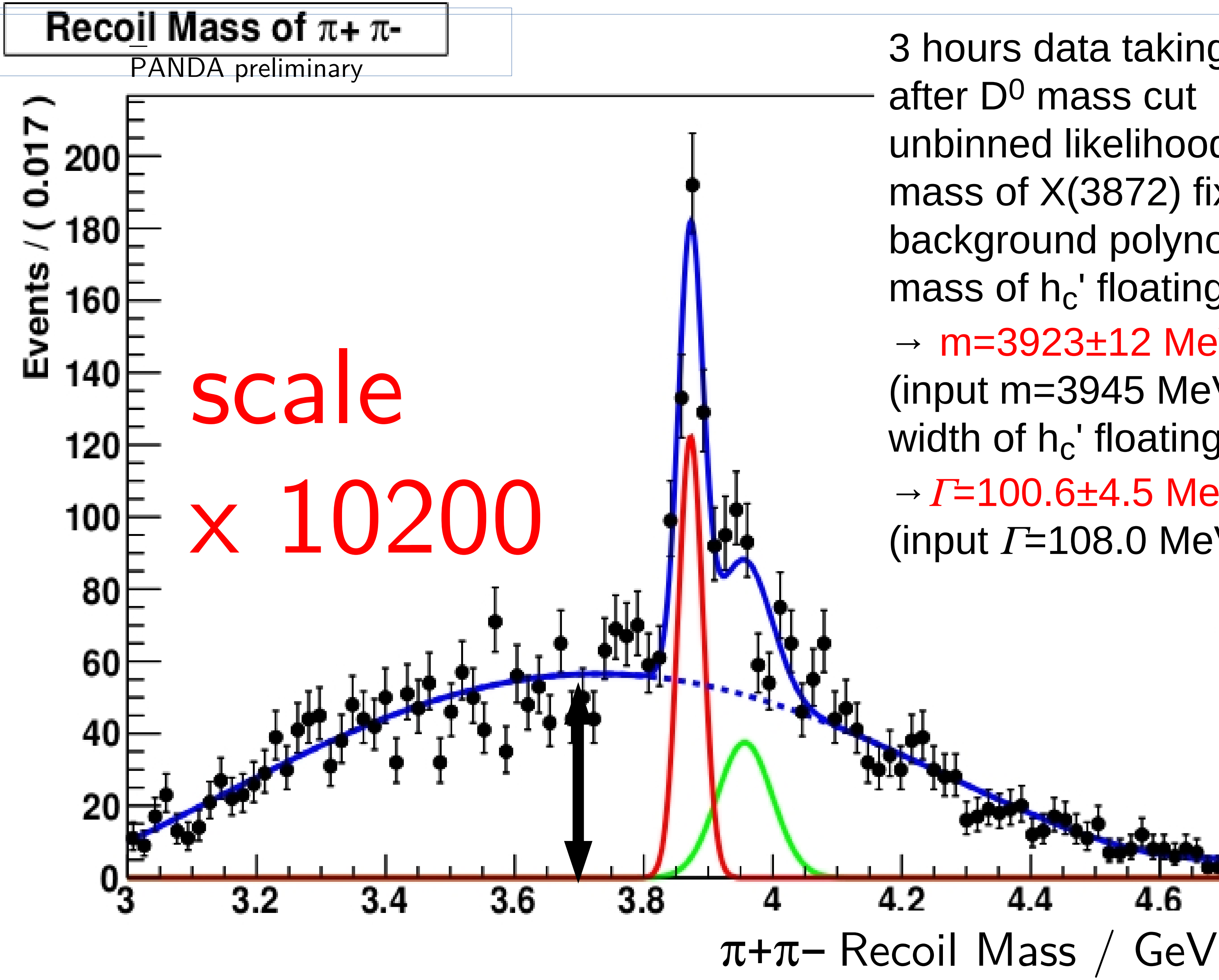
	Cross section	Reconstruction efficiency
Signal	4.5 nb	8.3%
Background	43 mb	1.6×10^{-5}

Signal cross section is required to achieve $S/\sqrt{(S+B)} \geq 10$ in 6 weeks

→ suppress background by cuts:
- D^0 invariant mass
  - $p_{lab}(\pi\pm) > 1.2$ GeV
  - vertex cut ± 0.1 cm (z)



M. Galuska, S. Reiter, E. Prencipe, S. Spataro, S.L., arXiv:1311.7597[hep-ex]



3 hours data taking
after D^0 mass cut
unbinned likelihood fit
mass of X(3872) fixed
background polynomial
mass of h_c' floating
→ m=3923±12 MeV
(input m=3945 MeV)
width of h_c' floating
→ Γ=100.6±4.5 MeV
(input Γ=108.0 MeV)

M. Galuska, S. Reiter, E. Prencipe, S. Spataro, S.L., arXiv:1311.7597[hep-ex]