Charm Potential at *Belle II*

Giulia Casarosa

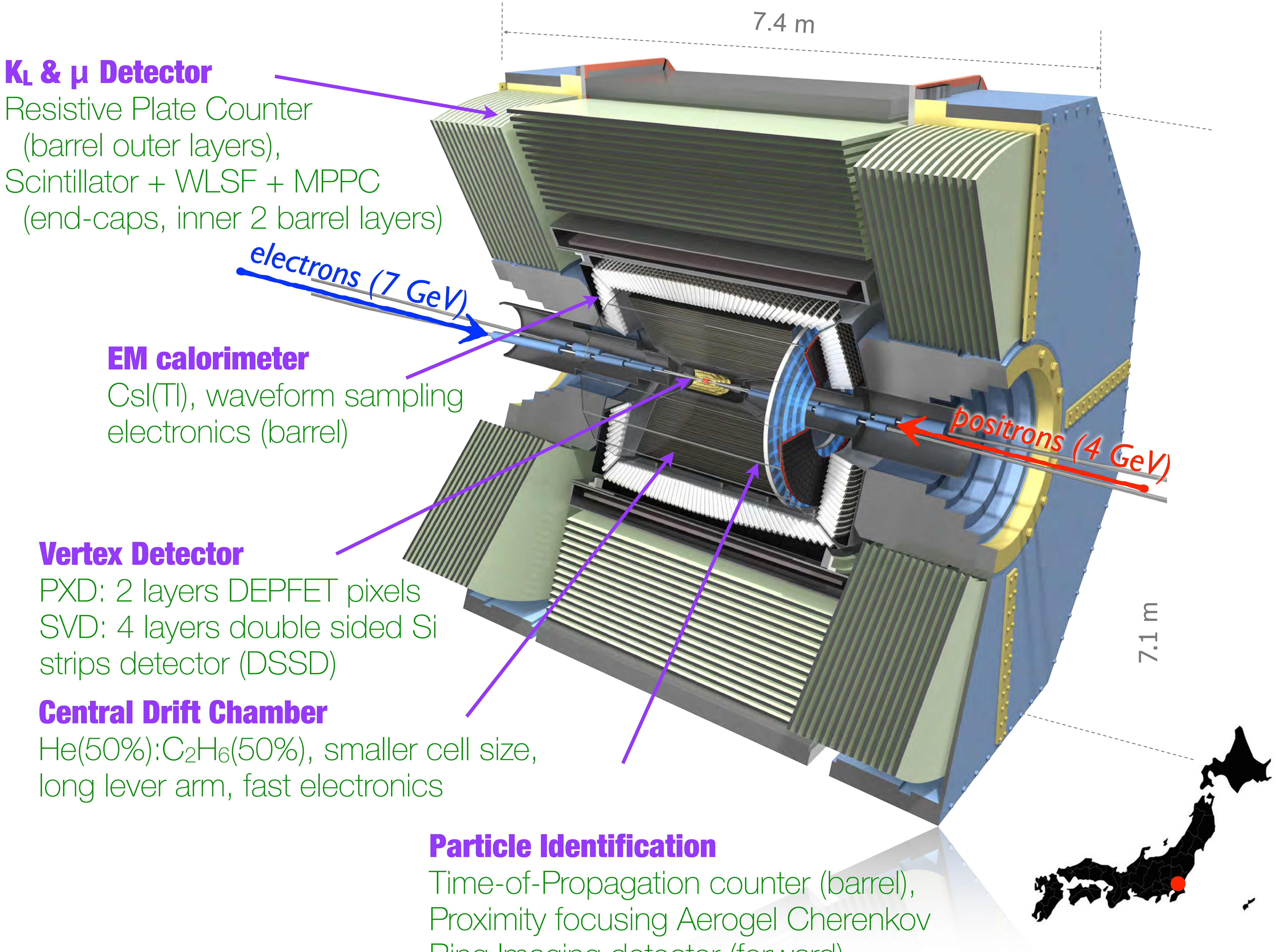
on behalf of the *Belle II* collaboration

Content

Belle II charm potential

Belle II is a multi-purpose detector installed at the IP of the high-luminosity B-Factory SuperKEKB (**target dataset 50 ab^{-1}**), located at the KEK Laboratory - Tsukuba, Japan

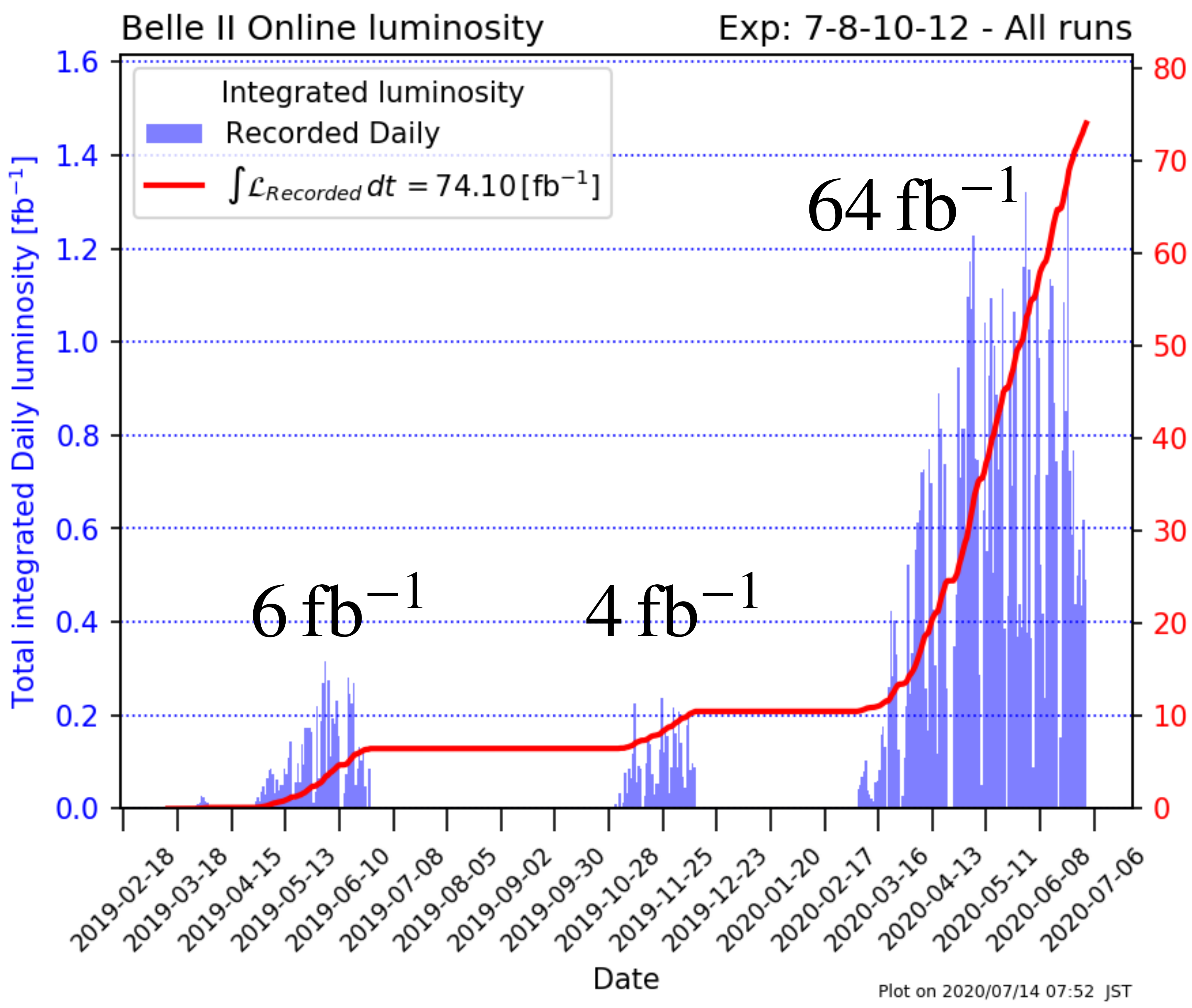
- ➡ *Where We Are*
- ➡ *Charm Prospects @ 50 ab^{-1}*
  VS
  Current Reconstruction Performance
  - *mixing & CPV*
  - *full charm-event reconstruction*
    - *rare/forbidden decays; leptonic & semileptonic decays; charm baryons*



Where We Are

SuperKEKB World Record Luminosity

- ➡ Data taking started in 2019, we collected roughly ~75 fb^{-1}, most of them in 2020
  - world-wide COVID-19 emergency did not stop SuperKEKB & ***Belle II*** operations
  - World Record luminosity by SuperKEKB on June 15th 2020, new WR: $2.4 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- ➡ work now mainly on re-discoveries
- ➡ collected dataset extremely useful to check reconstruction performance, resolutions and systematic effects …
- ➡ … but also for first publications, a few more in the pipeline



➡ physics measurements will benefit from the increase of statistics wrt Belle if:

- **the resolution is comparable with Belle, or better;**
- **systematic uncertainty is reduced too**

keep in mind

PTEP 2019, 123C01 (2019) [arXiv:1808.10567]

The Belle II Physics Book

Prospects @ 50 ab^{-1}

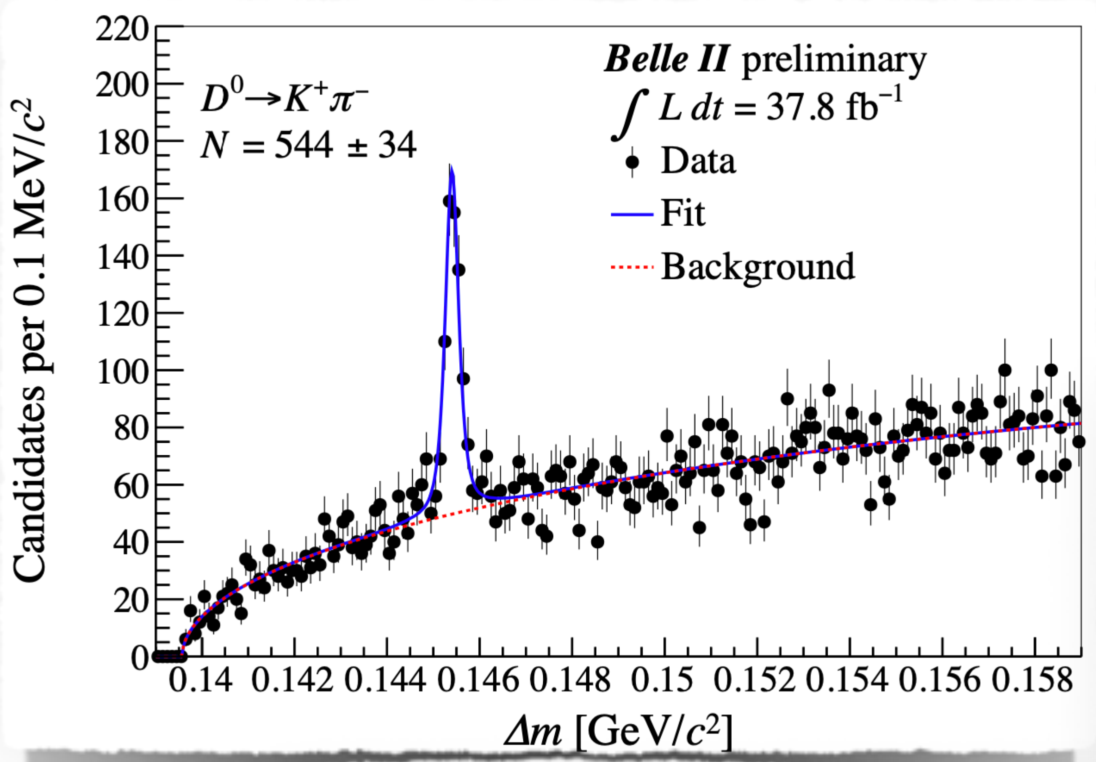
VS

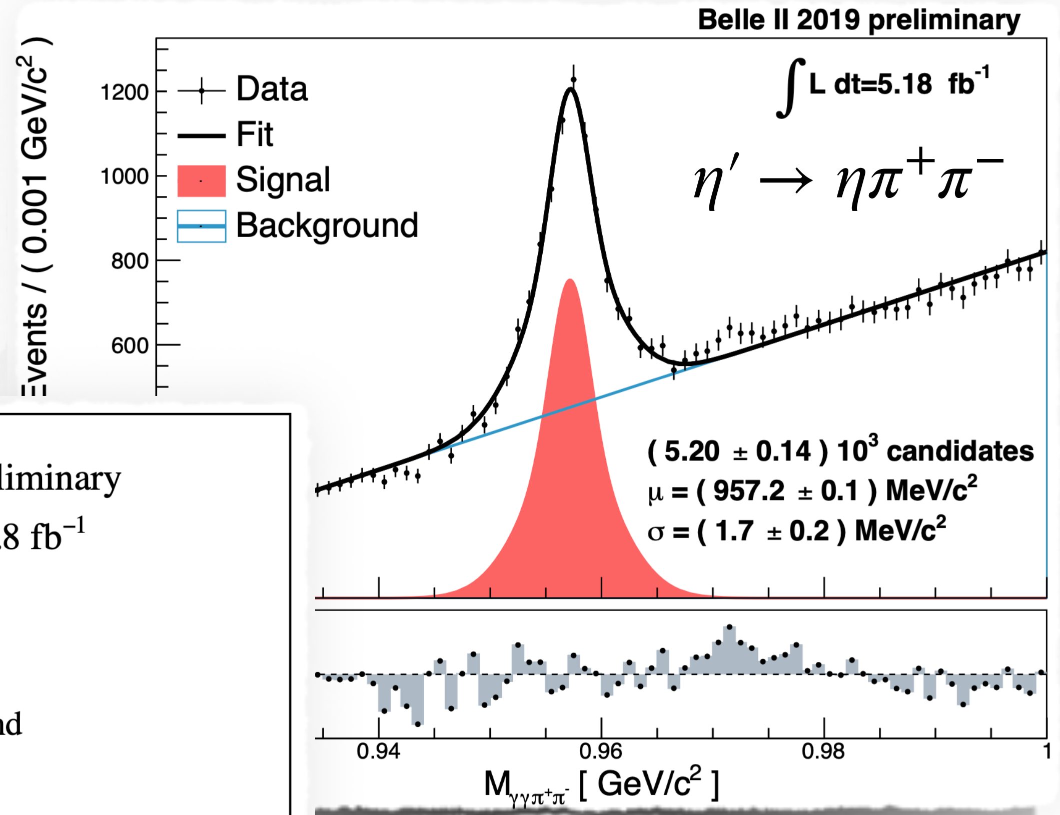
Current Reconstruction Performance

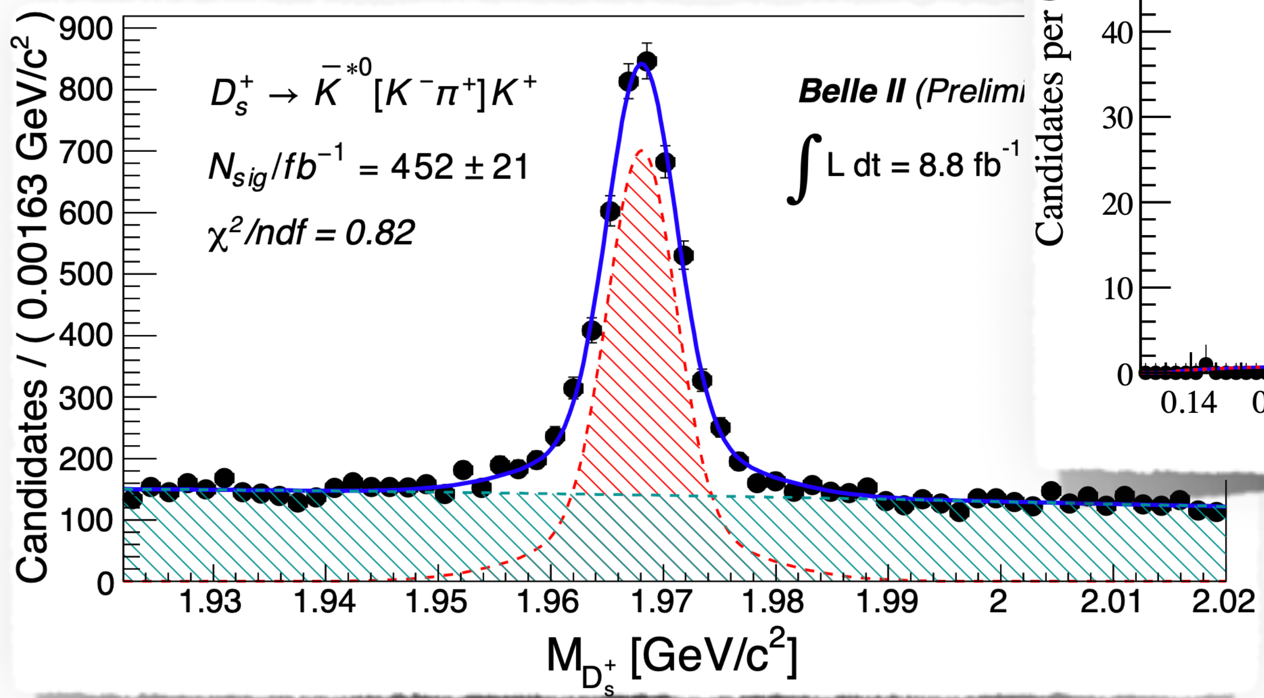
Belle II data

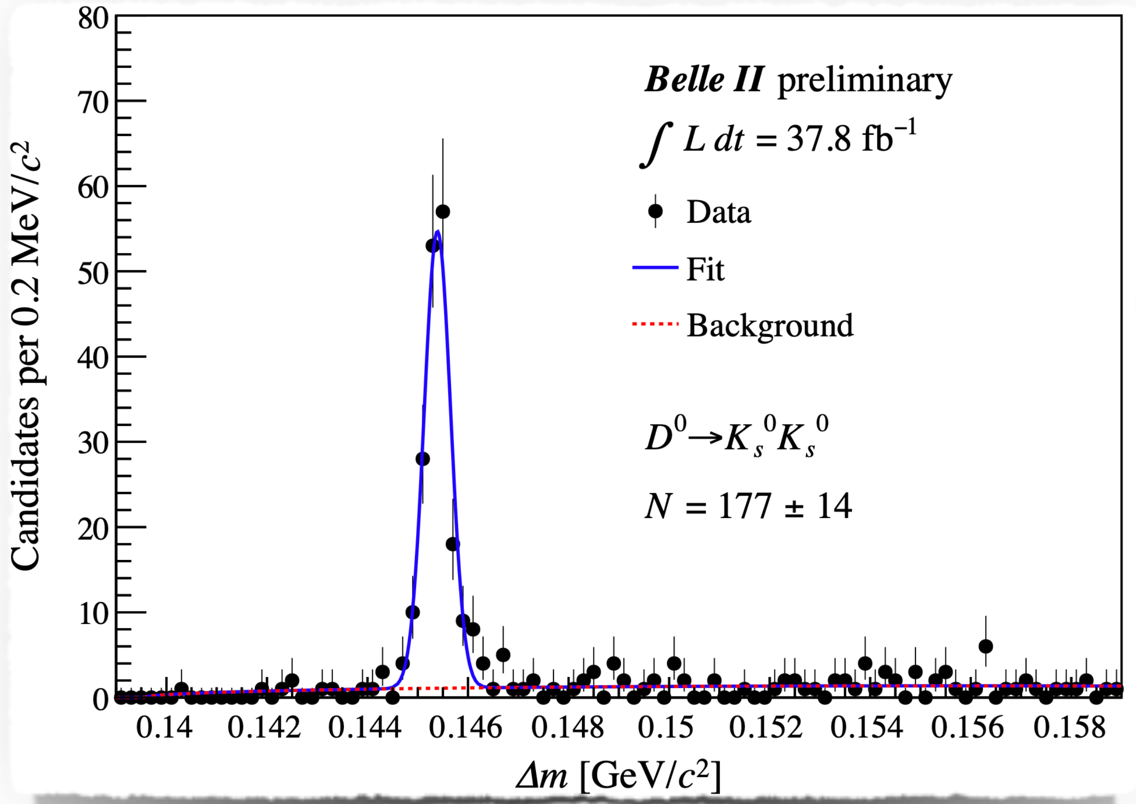
extrapolations based on Belle analysis & simulation

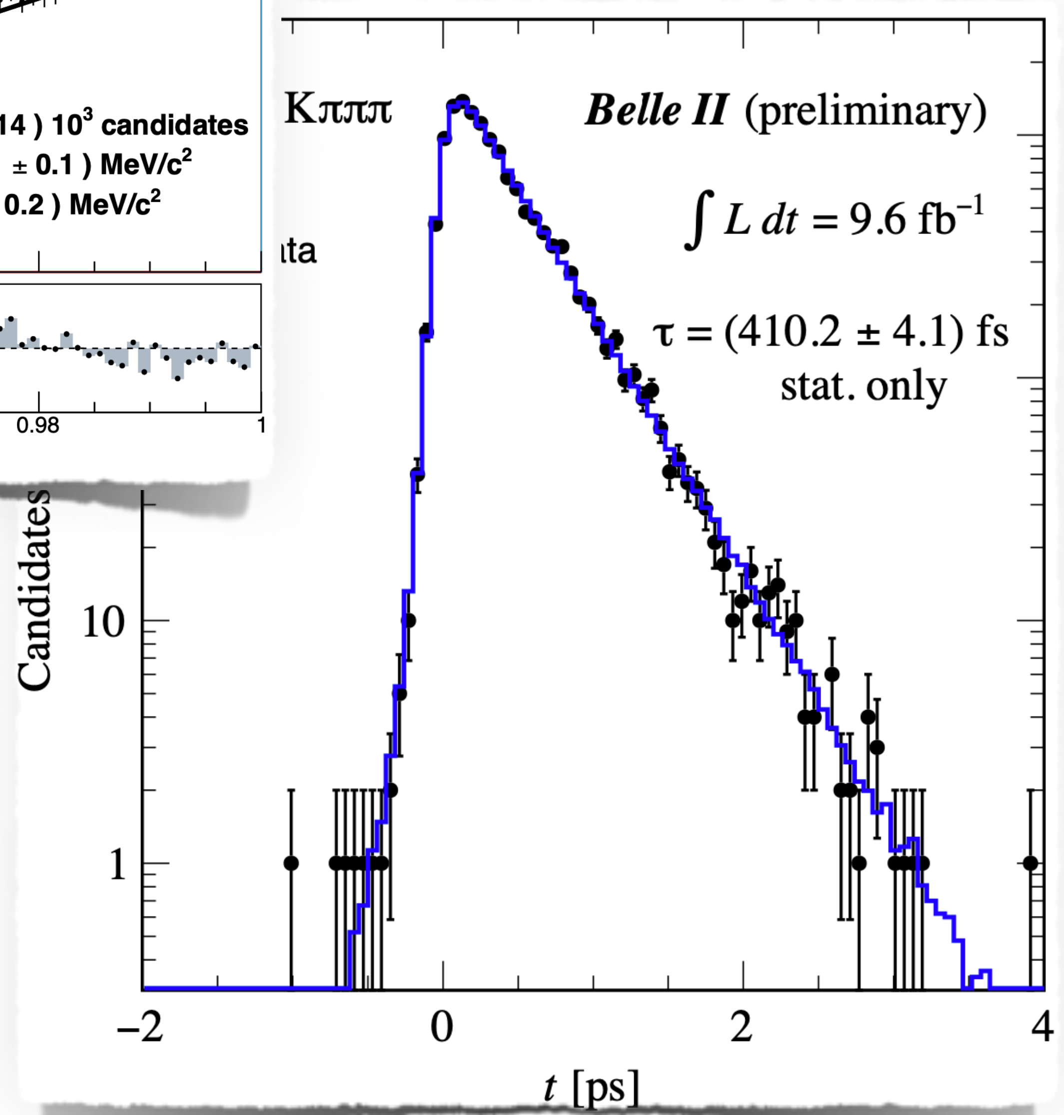
$$\sigma_{\mathrm{BelleII}} = \sqrt{\left(\sigma^2_{\mathrm{stat}} + \sigma^2_{\mathrm{sys}}\right)\cdot\frac{\mathscr{L}_{Belle}}{50\mathrm{ab}^{-1}} + \sigma^2_{\mathrm{irr}}}$$





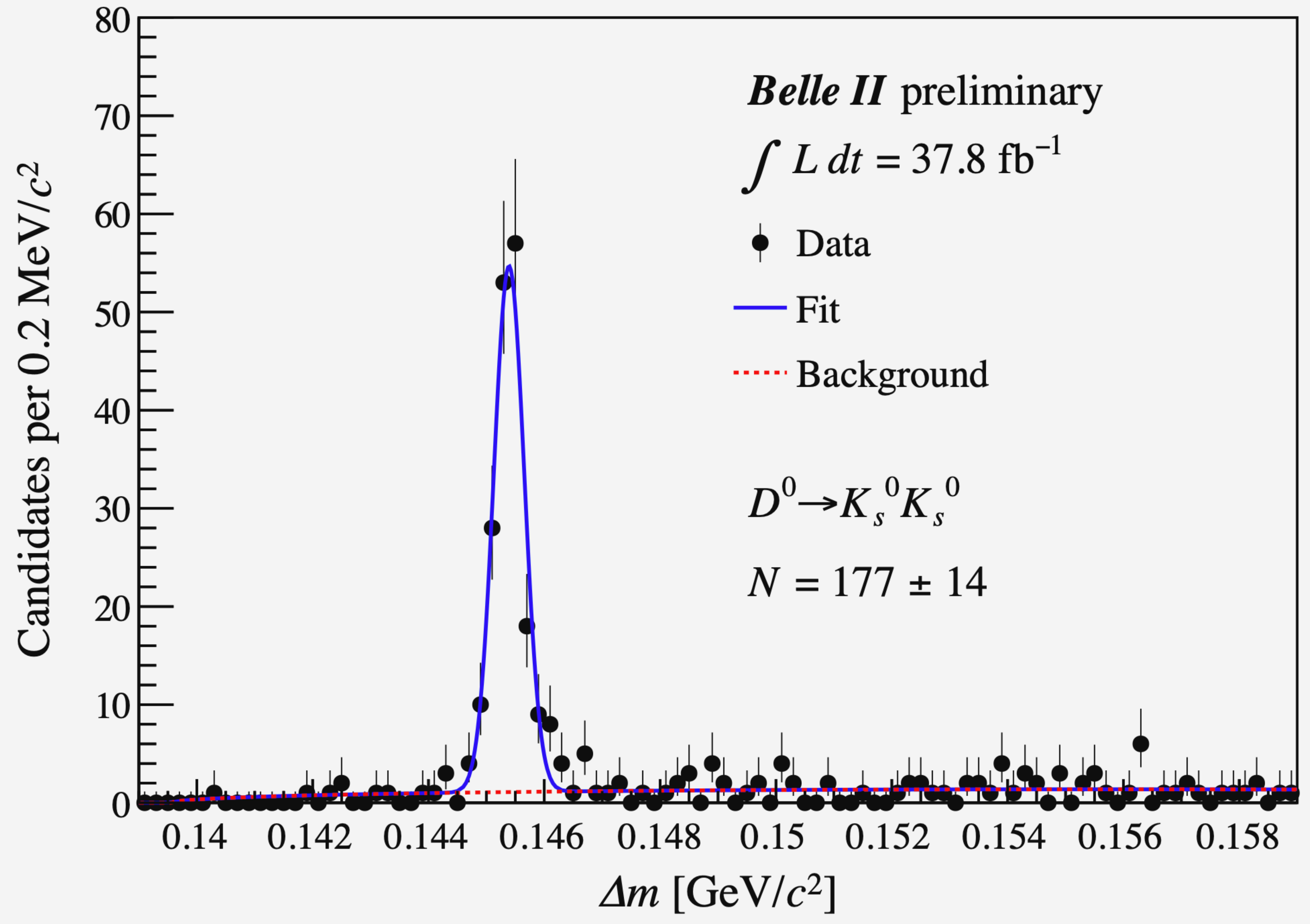






CP Violation

- time integrated CP asymmetries



CPV @ 50 ab^{-1}

based on extrapolations from Belle analysis

- ➡ Measurement of A_{CP} in several channels needed to overcome difficulties in computation of the SM prediction
  - e.g. use sum rules, estimating SU(3)$_F$ symmetry breaking effects (need A_{CP} and BR of SU(3)$_F$—connected channels)
- ➡ ***Belle II*** contribution will be important especially on **neutrals** in the final state
- ➡ A_{CP} will reach a precision of $o(10^{-4})$, also in channels with neutrals in the final state

Mode	$\mathcal{L}$ (fb^{-1})	A_{CP} (%)	Belle II 50 ab^{-1}
$D^0 \to K^+K^-$	976	$-0.32 \pm 0.21 \pm 0.09$	± 0.03
$D^0 \to \pi^+\pi^-$	976	$+0.55 \pm 0.36 \pm 0.09$	± 0.05
$D^0 \to \pi^0\pi^0$	966	$-0.03 \pm 0.64 \pm 0.10$	± 0.09
$D^0 \to K^0_S\pi^0$	966	$-0.21 \pm 0.16 \pm 0.07$	± 0.02
$D^0 \to K^0_S K^0_S$	921	$-0.02 \pm 1.53 \pm 0.02 \pm 0.17$	± 0.23
$D^0 \to K^0_S\eta$	791	$+0.54 \pm 0.51 \pm 0.16$	± 0.07
$D^0 \to K^0_S\eta'$	791	$+0.98 \pm 0.67 \pm 0.14$	± 0.09
$D^0 \to \pi^+\pi^-\pi^0$	532	$+0.43 \pm 1.30$	± 0.13
$D^0 \to K^+\pi^-\pi^0$	281	-0.60 ± 5.30	± 0.40
$D^0 \to K^+\pi^-\pi^+\pi^-$	281	-1.80 ± 4.40	± 0.33
$D^+ \to \phi\pi^+$	955	$+0.51 \pm 0.28 \pm 0.05$	± 0.04
$D^+ \to \pi^+\pi^0$	921	$+2.31 \pm 1.24 \pm 0.23$	± 0.17
$D^+ \to \eta\pi^+$	791	$+1.74 \pm 1.13 \pm 0.19$	± 0.14
$D^+ \to \eta'\pi^+$	791	$-0.12 \pm 1.12 \pm 0.17$	± 0.14
$D^+ \to K^0_S\pi^+$	977	$-0.36 \pm 0.09 \pm 0.07$	± 0.02
$D^+ \to K^0_S K^+$	977	$-0.25 \pm 0.28 \pm 0.14$	± 0.04
$D^+_s \to K^0_S\pi^+$	673	$+5.45 \pm 2.50 \pm 0.33$	± 0.29
$D^+_s \to K^0_S K^+$	673	$+0.12 \pm 0.36 \pm 0.22$	± 0.05

$D^+_s \to K^+\pi^0$

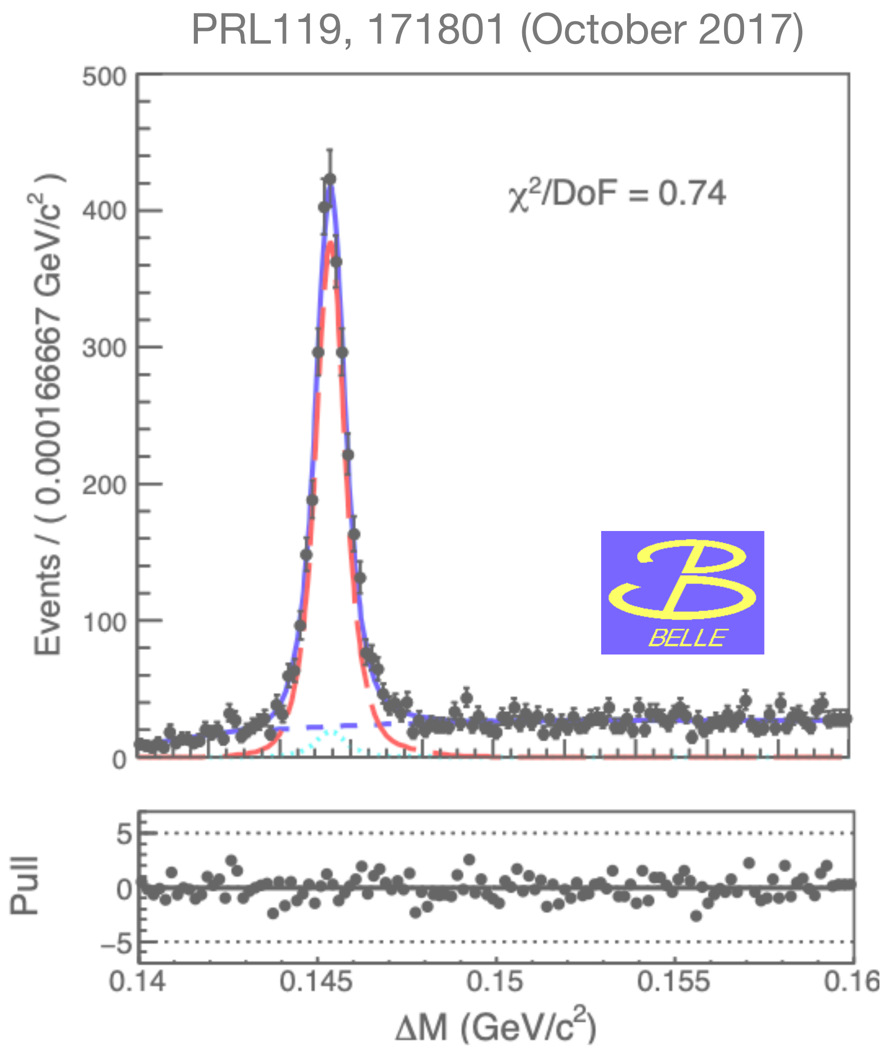
note: this is not a complete list

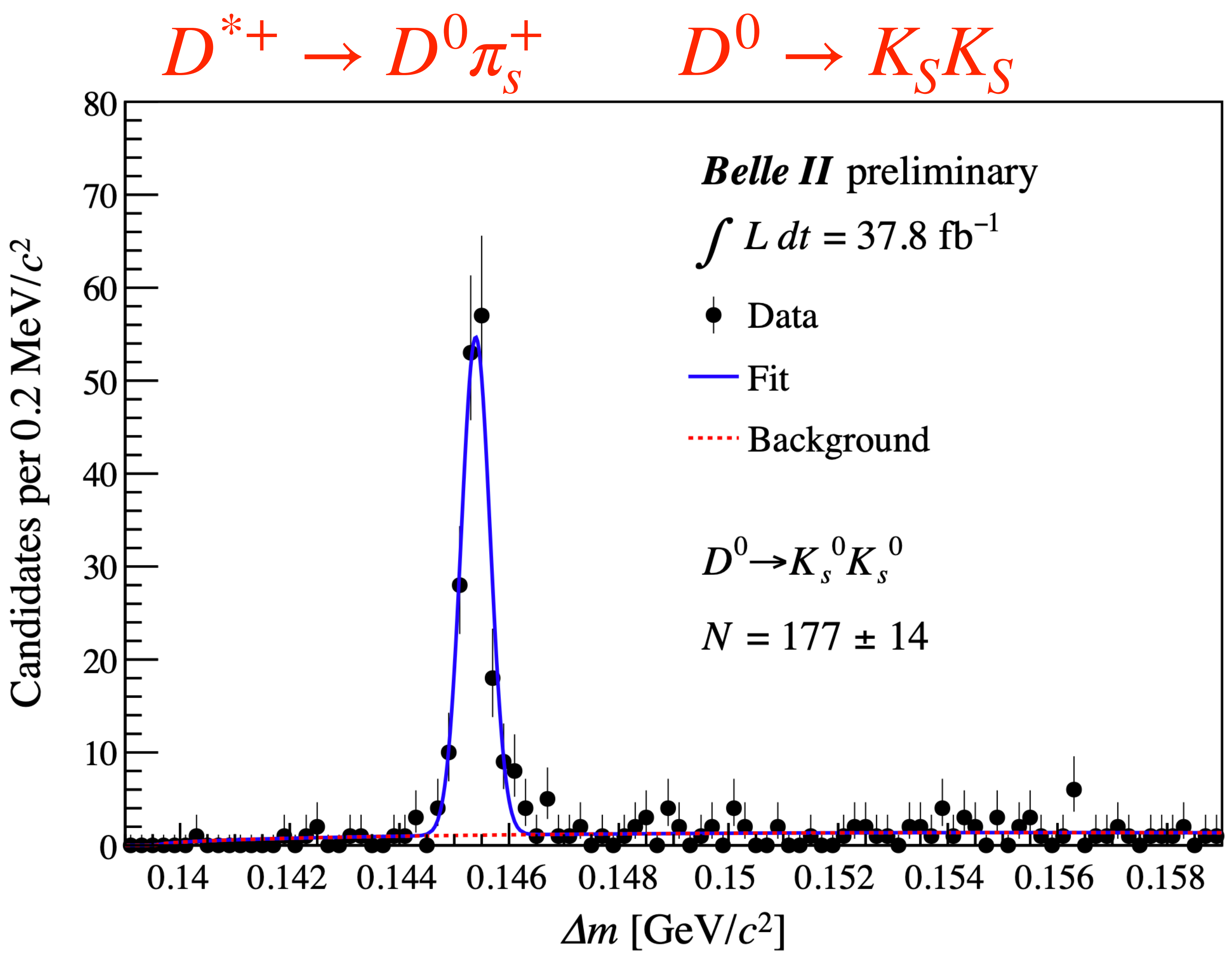
$D^0 \to K_S K_S$ and $D^0 \to K_S \pi^0$ @ Belle II

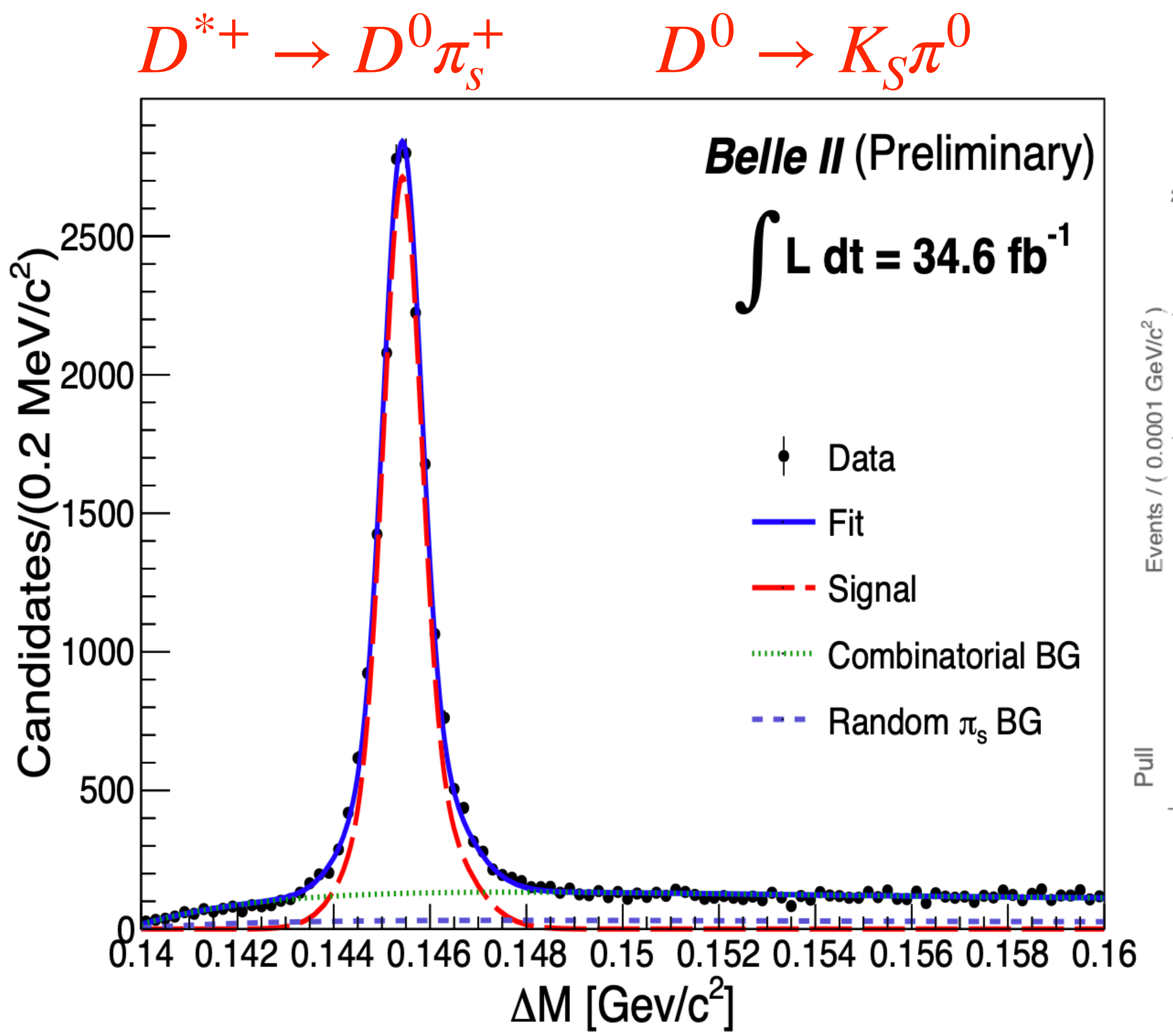
reconstruction performance

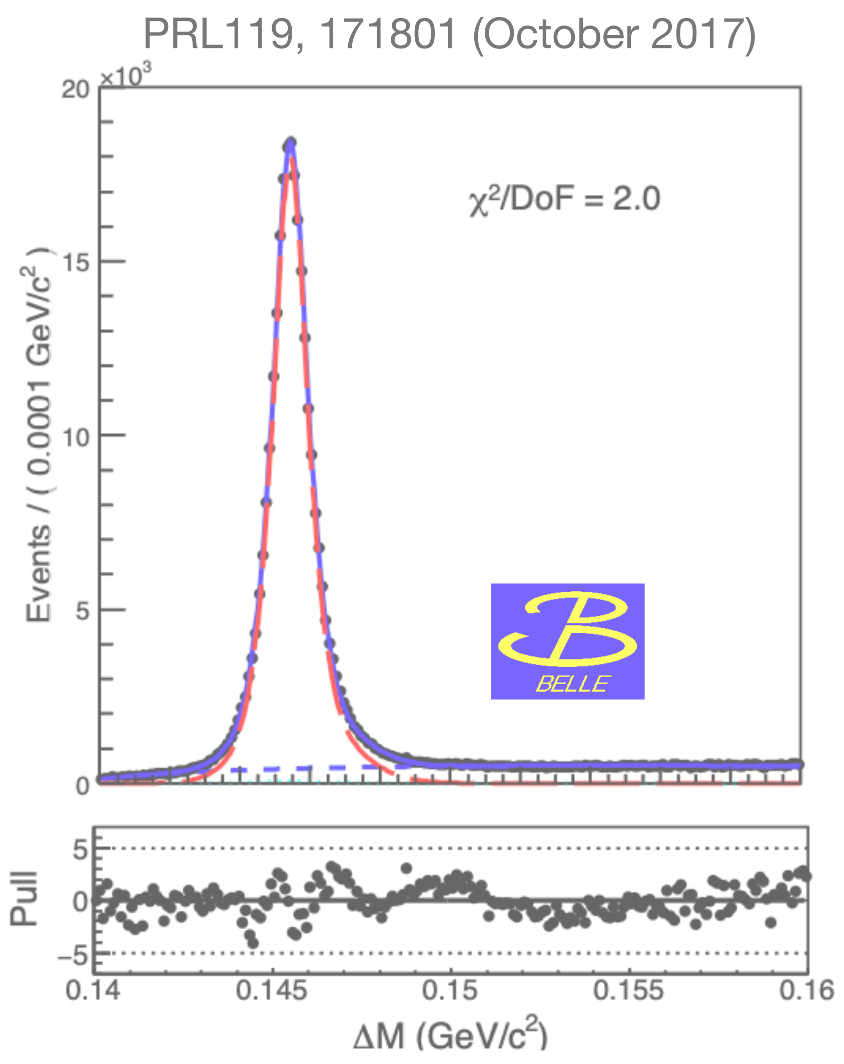
➡ Very good performance of the reconstruction, ***Belle II*** is approaching Belle performance after just 1.5 year of data taking, still there is room for improvements

- can do only a *qualitative* comparison with Belle, different selections applied



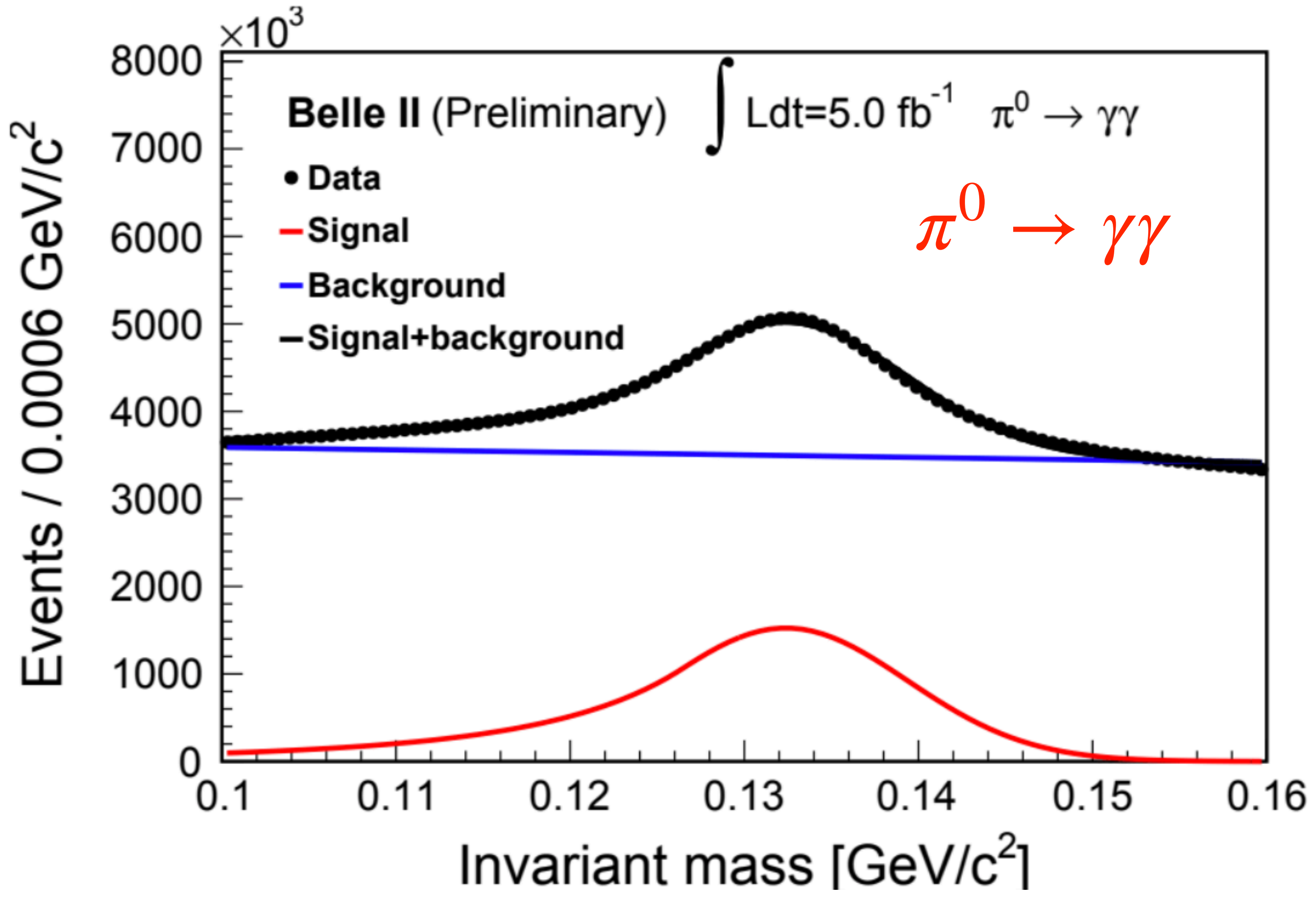


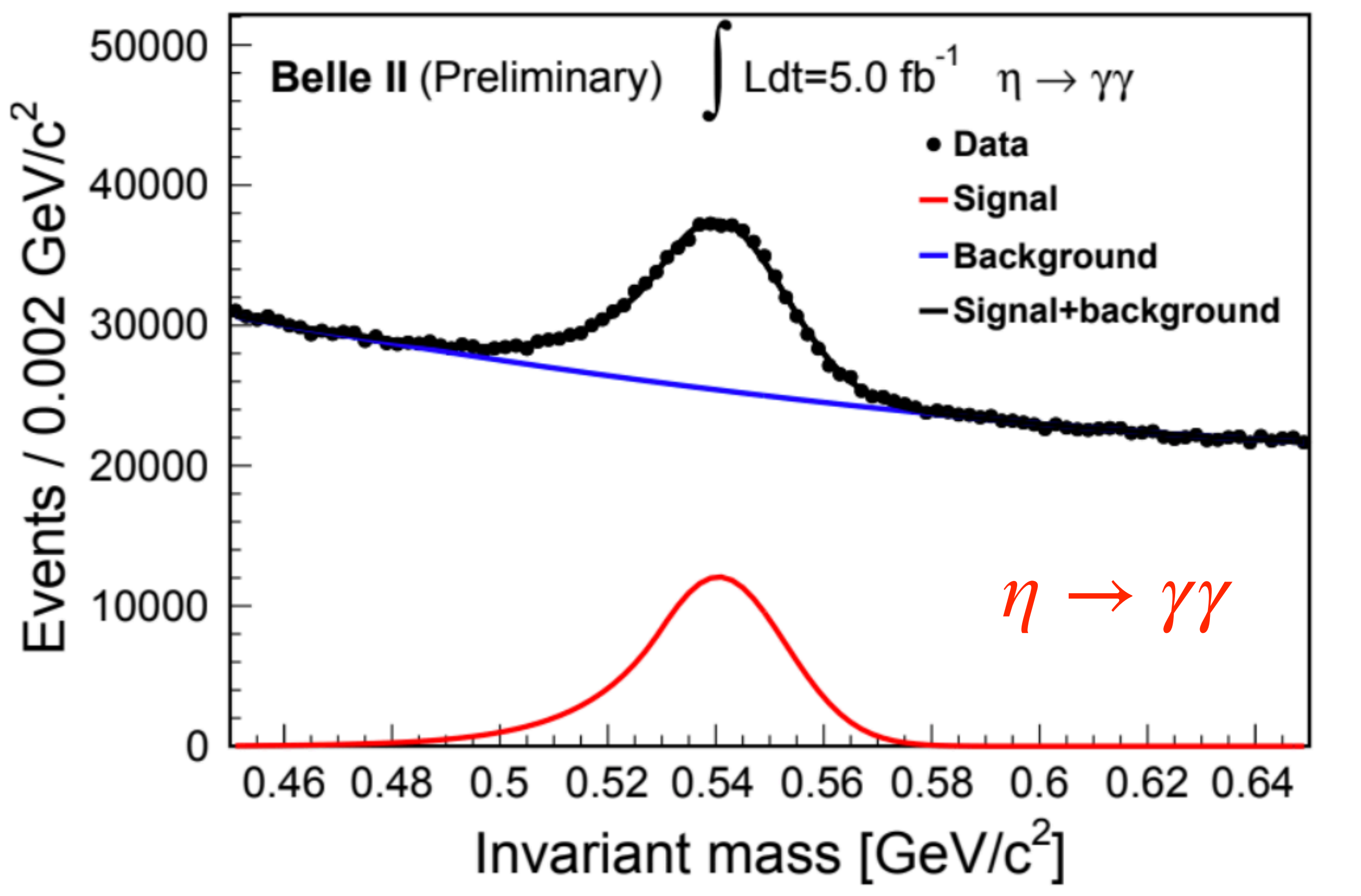


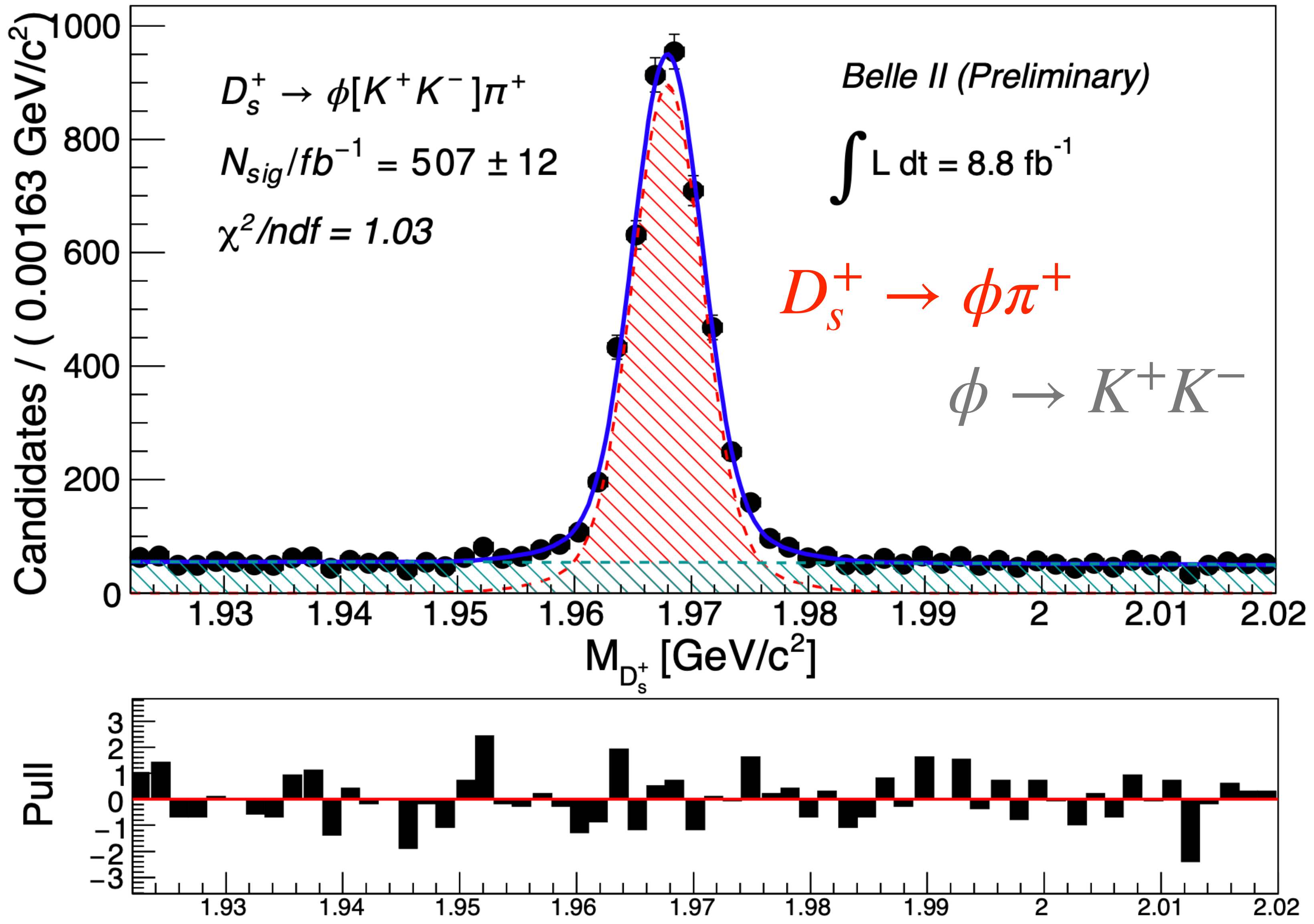


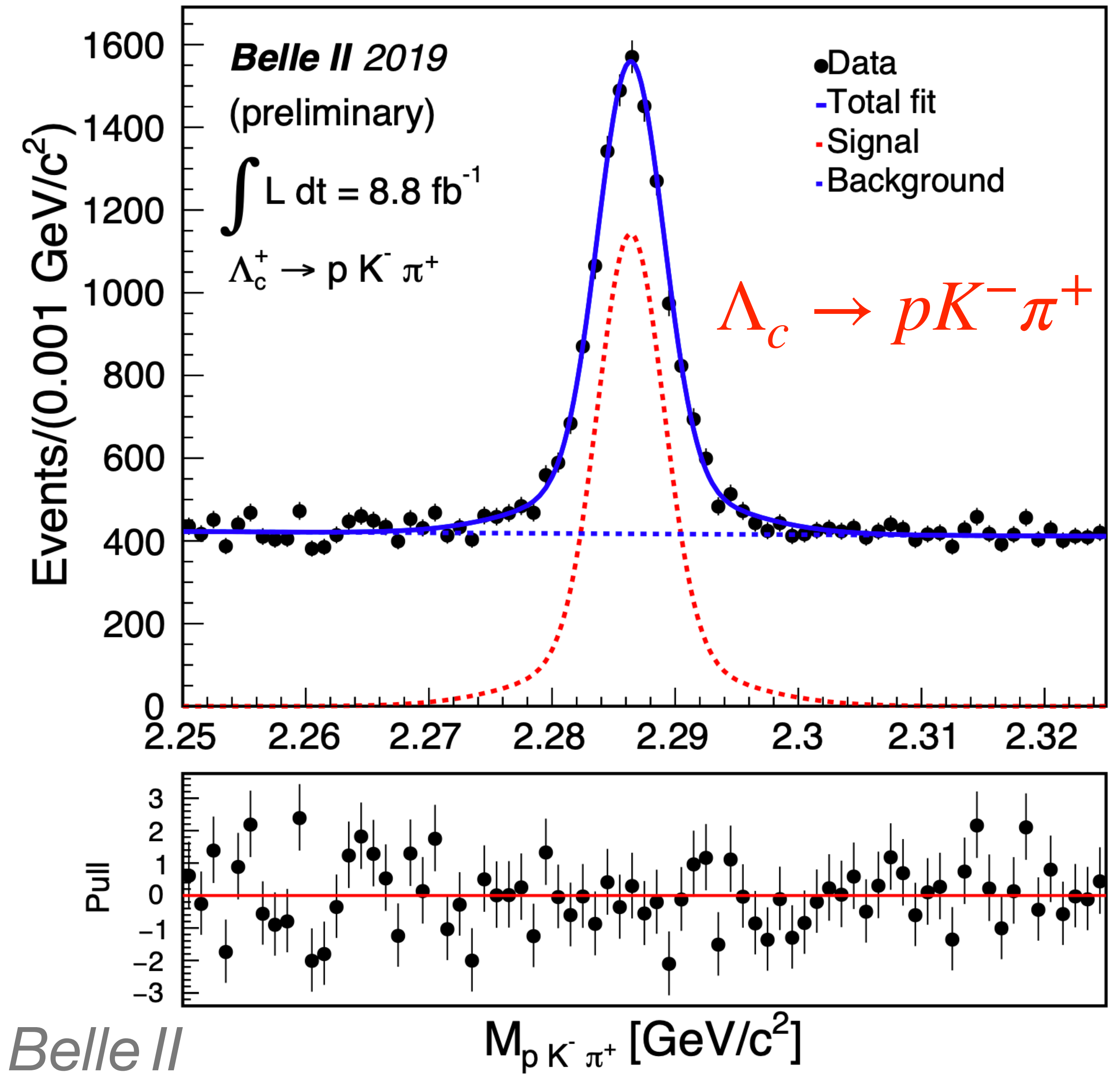
Ds, Λc, neutrals Reconstruction @ Belle II

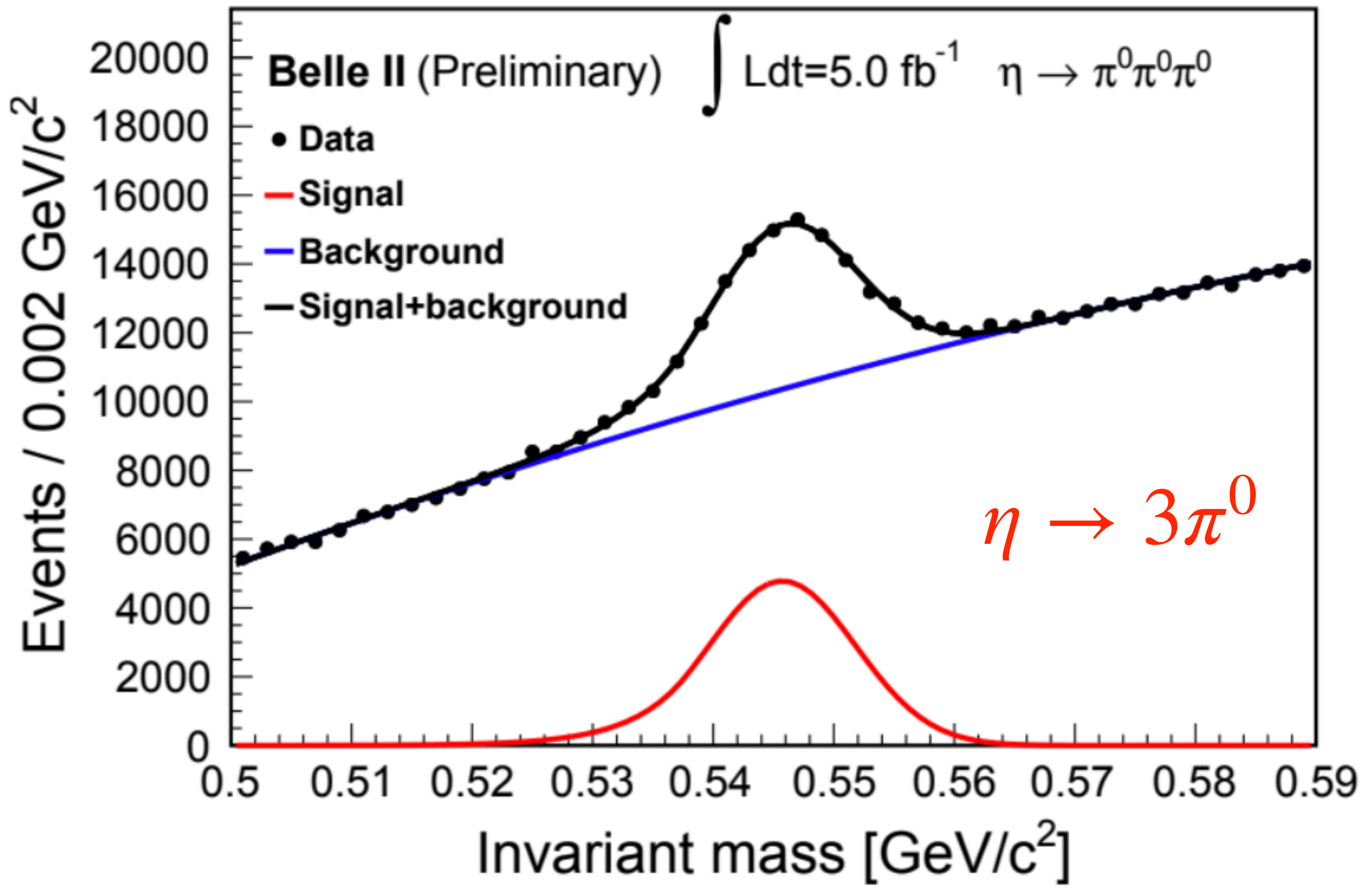
reconstruction being checked in several other modes

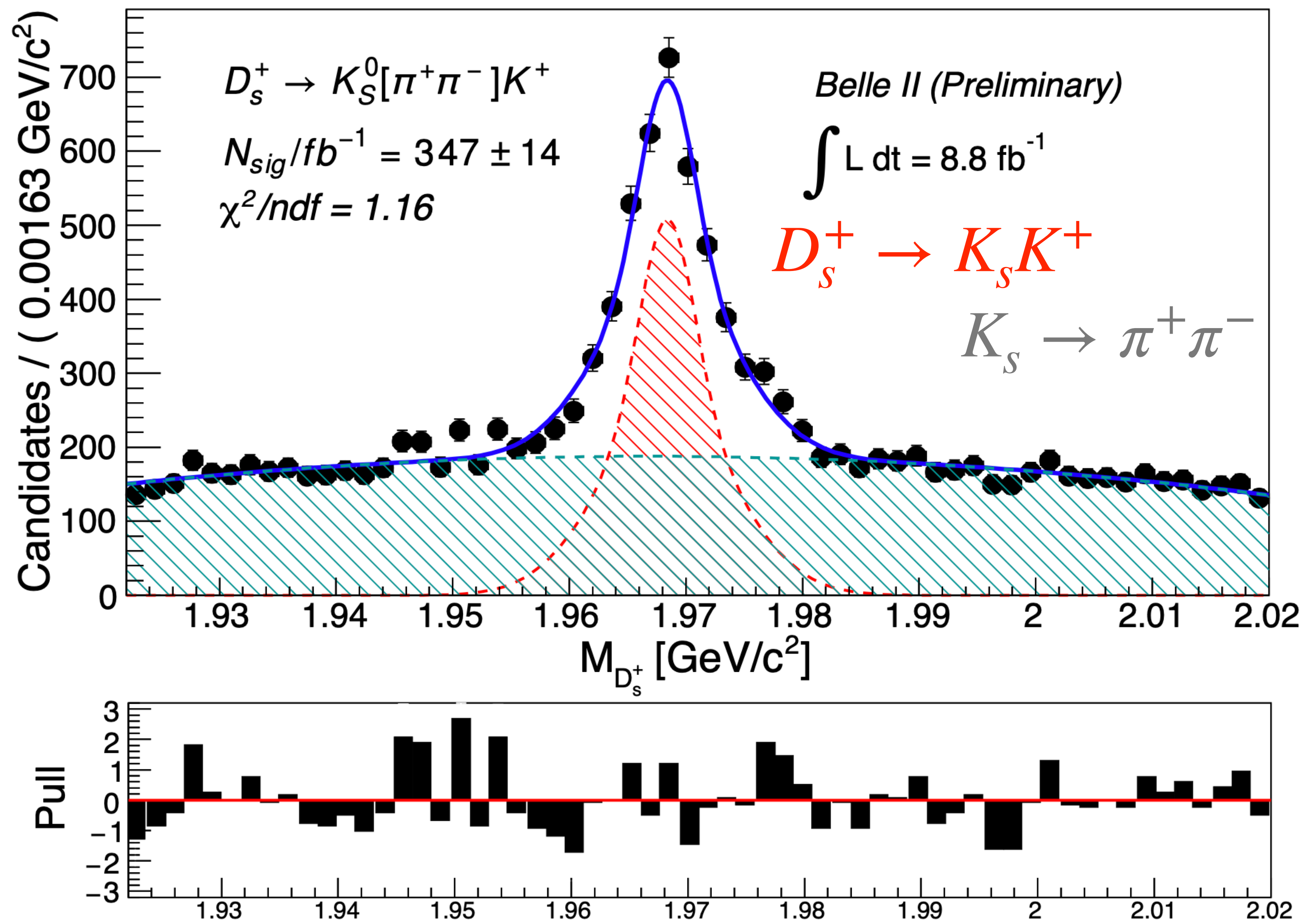






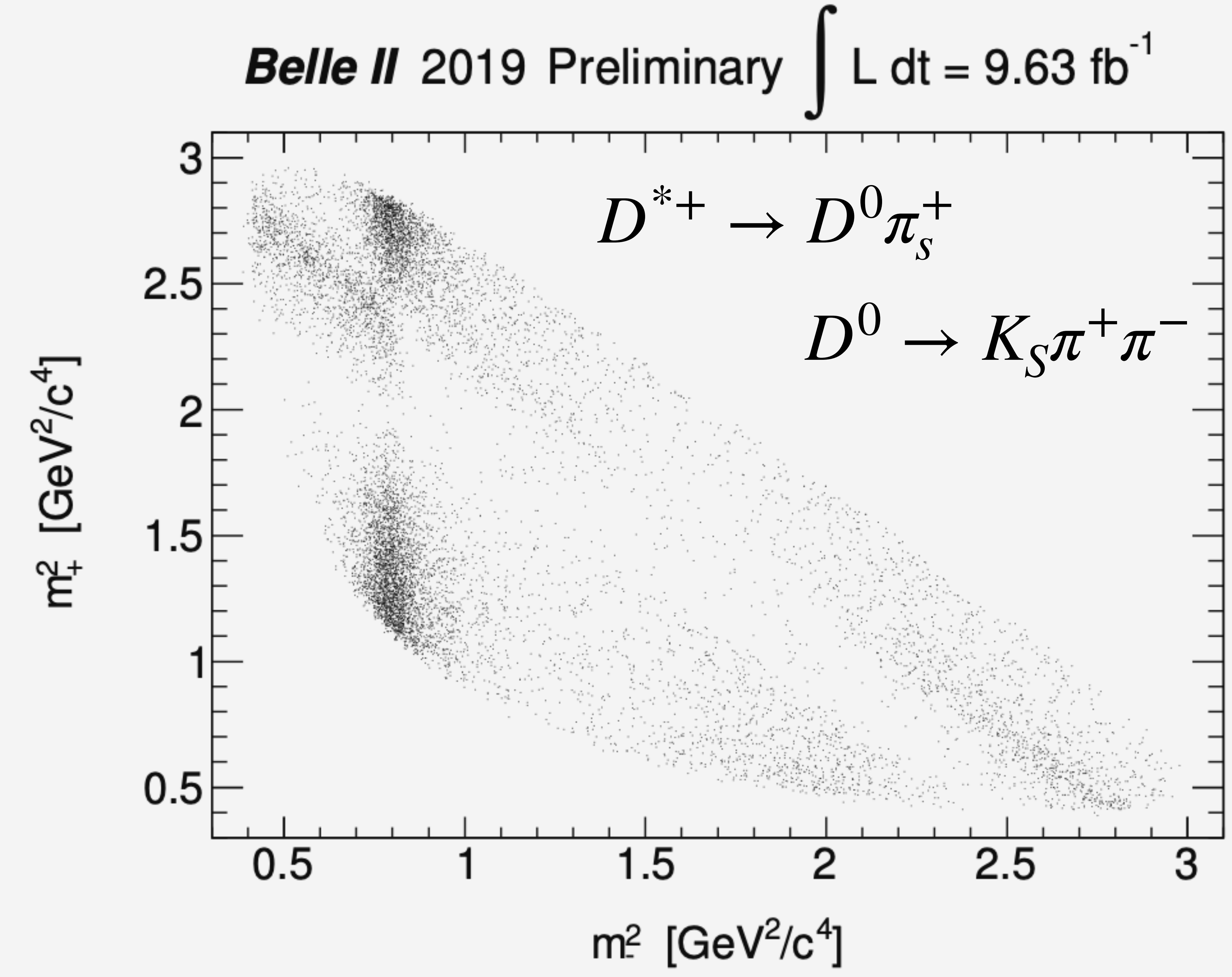






Mixing & CP Violation

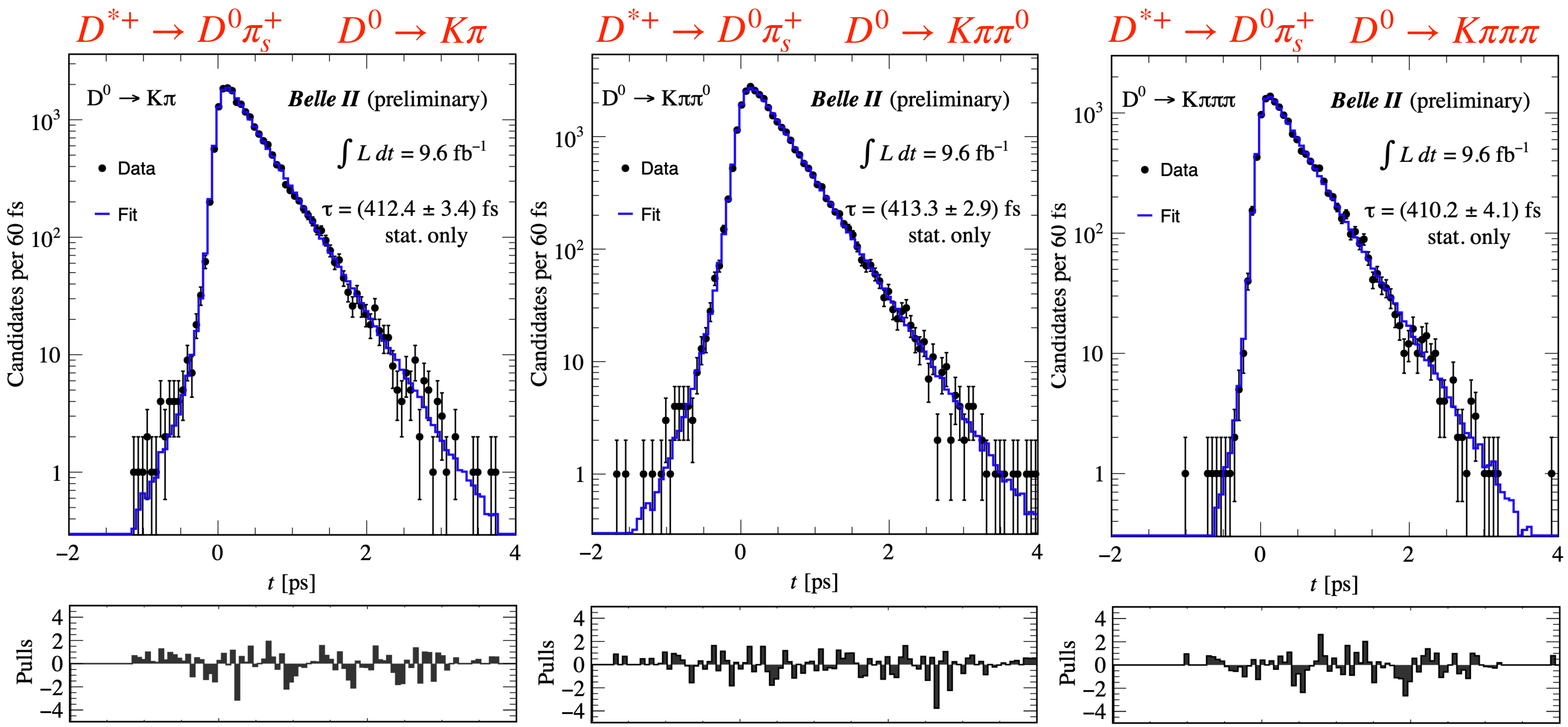
- *bonus*: D^0 lifetime
- wrong-sign decays
- $D^0 \to K_S \pi^+ \pi^-$ Dalitz plot

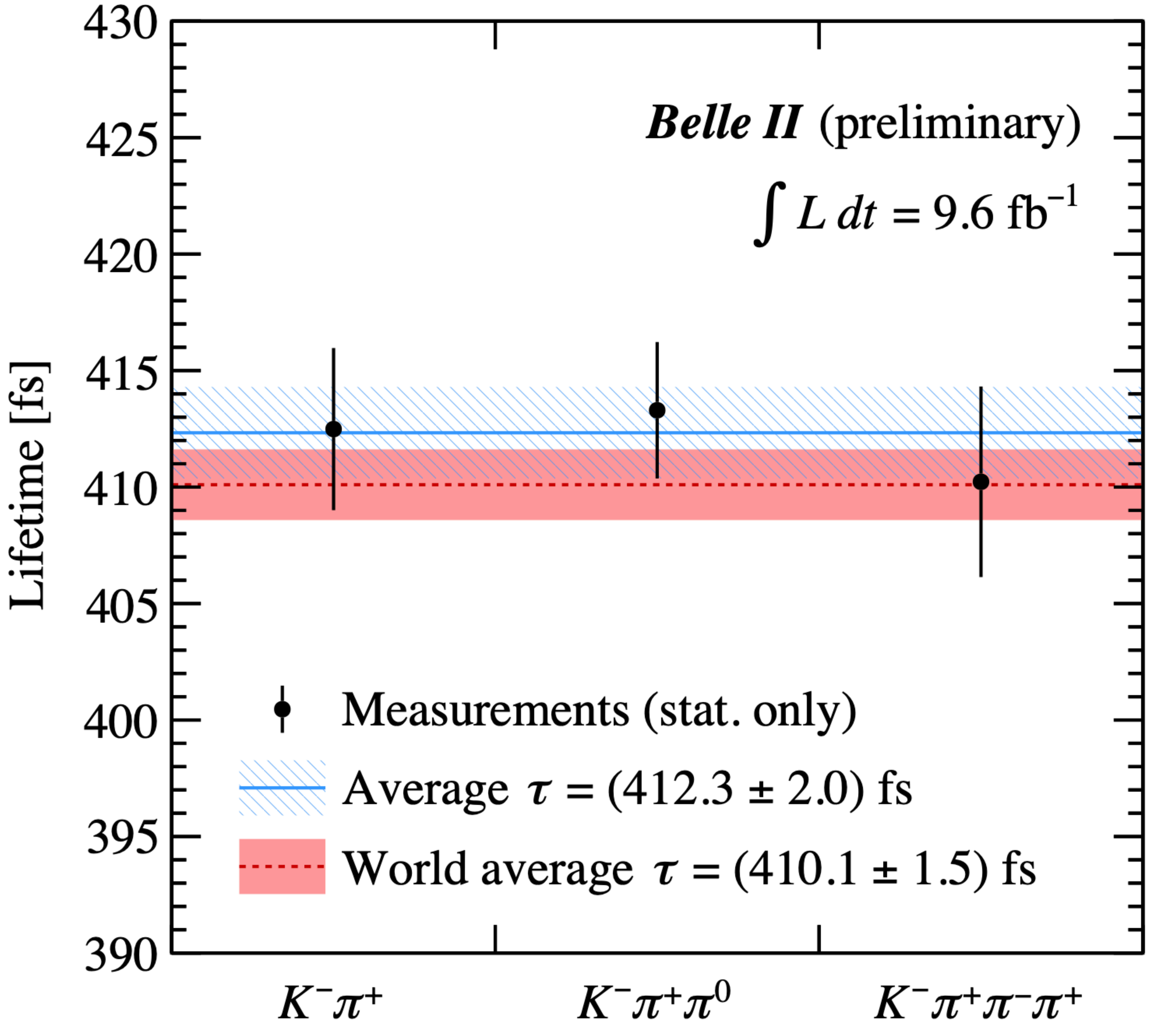


D^0 Lifetime Measurement @ Belle II

full check-up of detector & reconstruction performance

➡ Reconstruct the D*-tagged D^0 mesons in 3 signal channels, fit the proper time distribution with unbinned ML fit, using per-candidate proper time errors





extracted lifetime compatible with WA, statistical error comparable to WA with just 10 fb⁻¹

Improved Proper Time Resolution

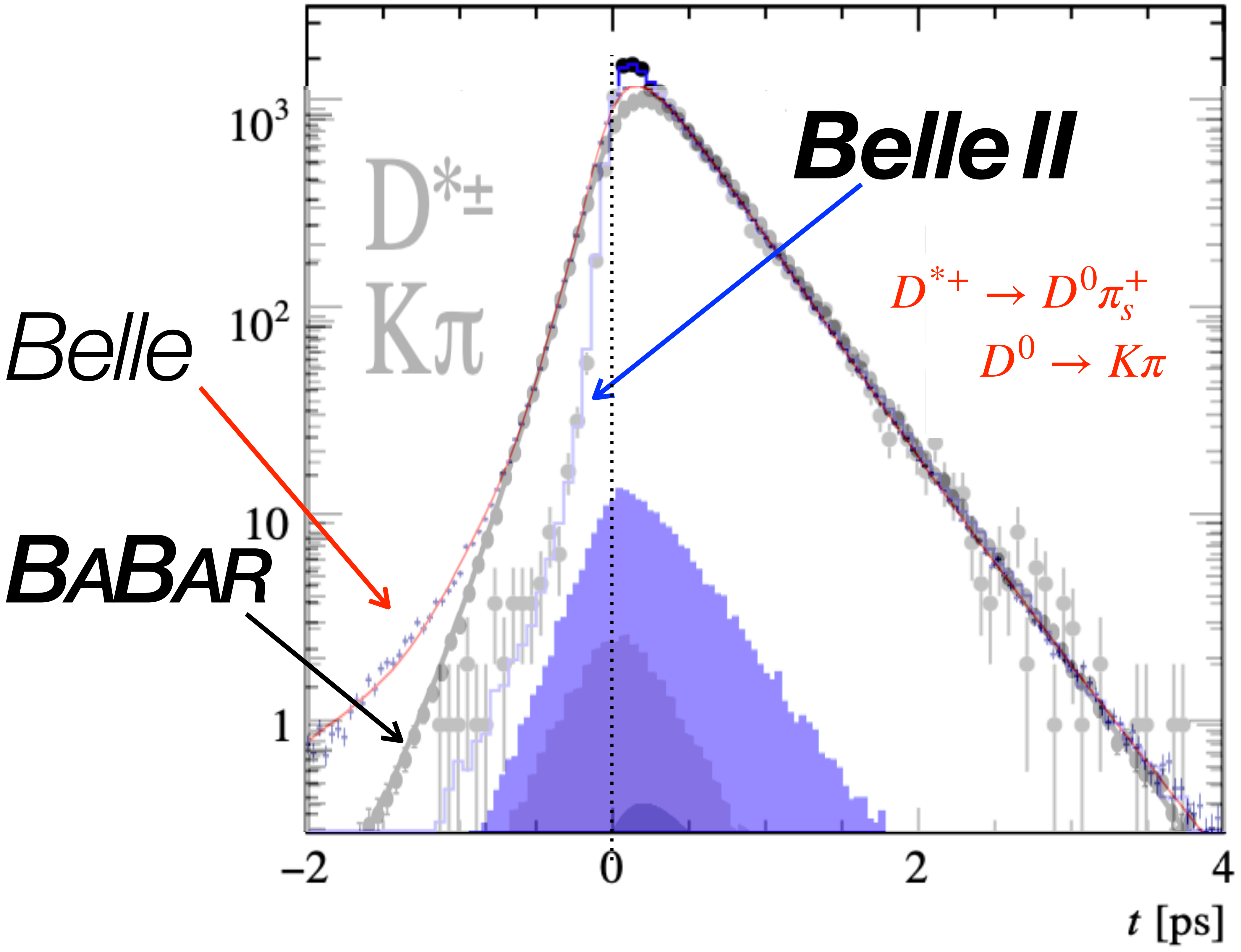
impact on time-dependent measurements

➡ Proper time resolution at ***Belle II*** is a factor 2 better than *Belle* & ***BABAR*** thanks to a better-performing vertex detector

- improved precision on mixing and CPV observables in time dependent analysis
- Toy MC to estimate the impact on **WS $D^0 \to K\pi$** analysis (almost systematically free):

estimated error on	current HFLAV	Belle scaled to 50/ab	Toy MC 50/ab, CPV
x' (%)	–	(*) 0.45	0.15
x'^2 (%)	–	0.009	–
y' (%)	–	0.16	0.10
|q/p|	~ 0.09	–	0.051
Φ (º)	~ 9	–	5.7

- resolution improvement visible at $t < 0$:



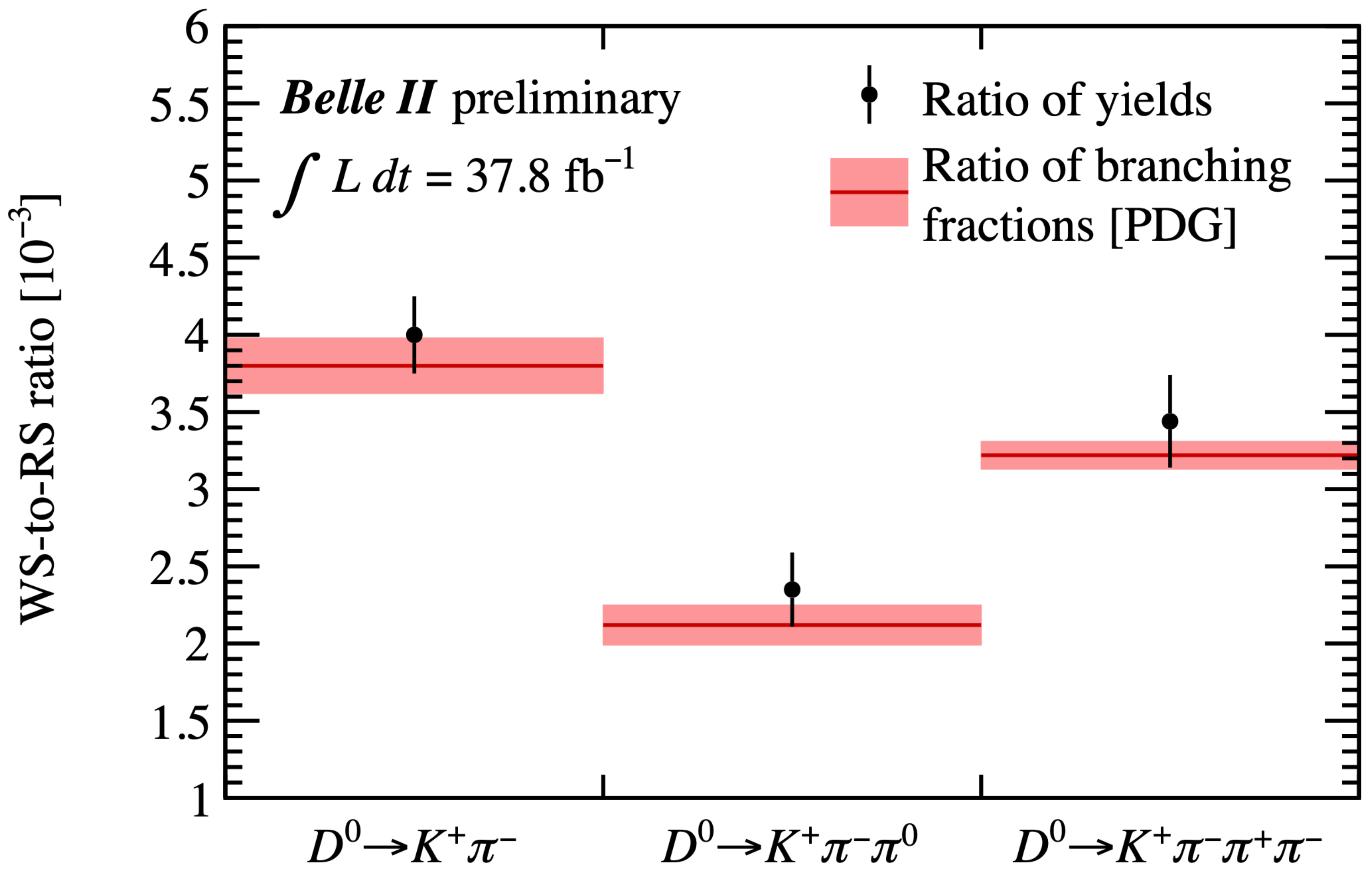
(*) measurement NOT sensitive to x', the error is computed from the error on x'^2

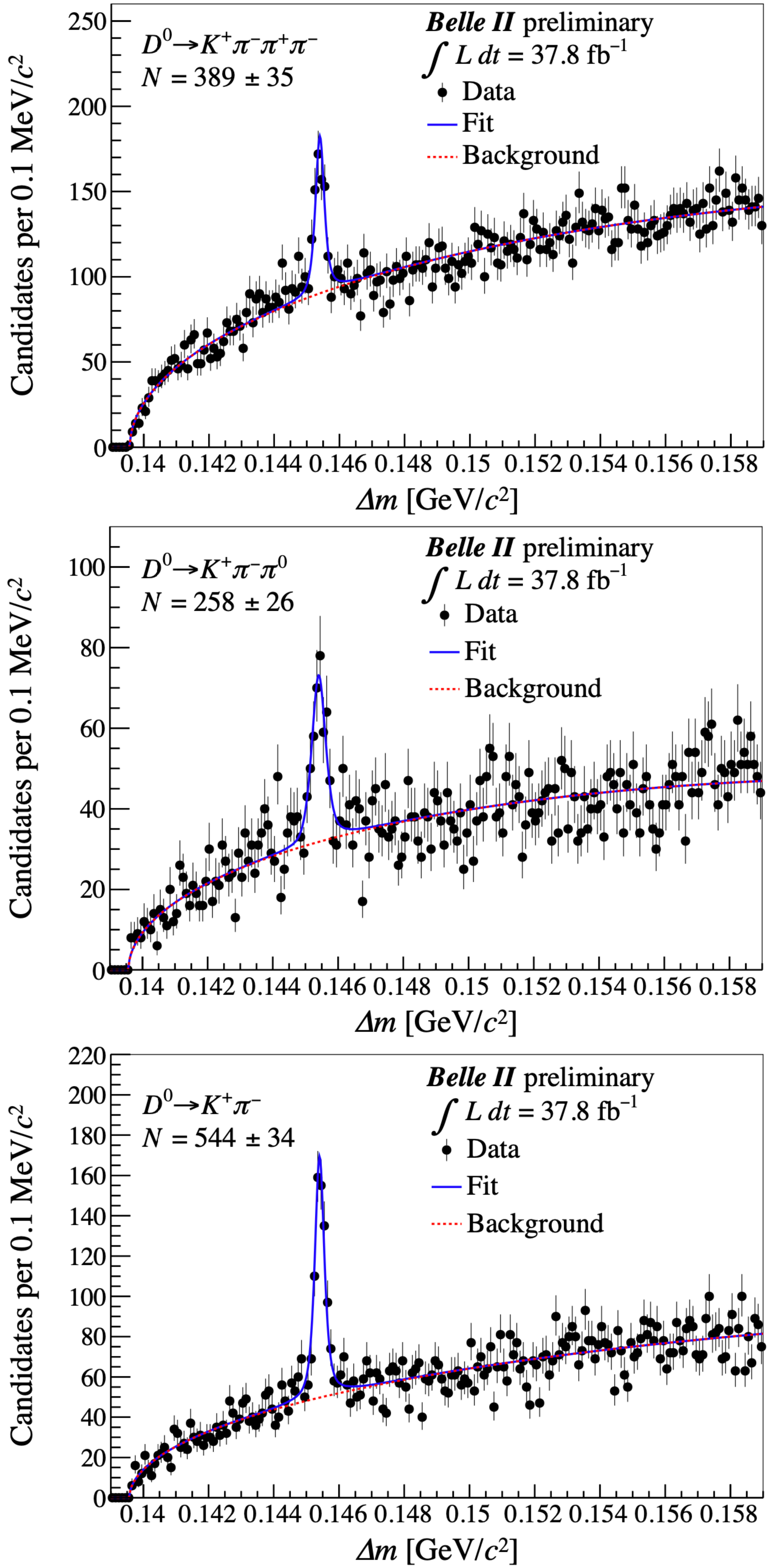
Wrong Sign D⁰ Decays

reconstruction performance

➡ Reconstruct RS & WS decays, extract PDF from RS and use it to fit the WS distributions

- compute the WS-to-RS ratio of yields, expected to be equivalent to the ratio of branching ratios (at first order):





$D^{*+} \to D^0 \pi_s^+$
$D^0 \to K\pi\pi\pi$

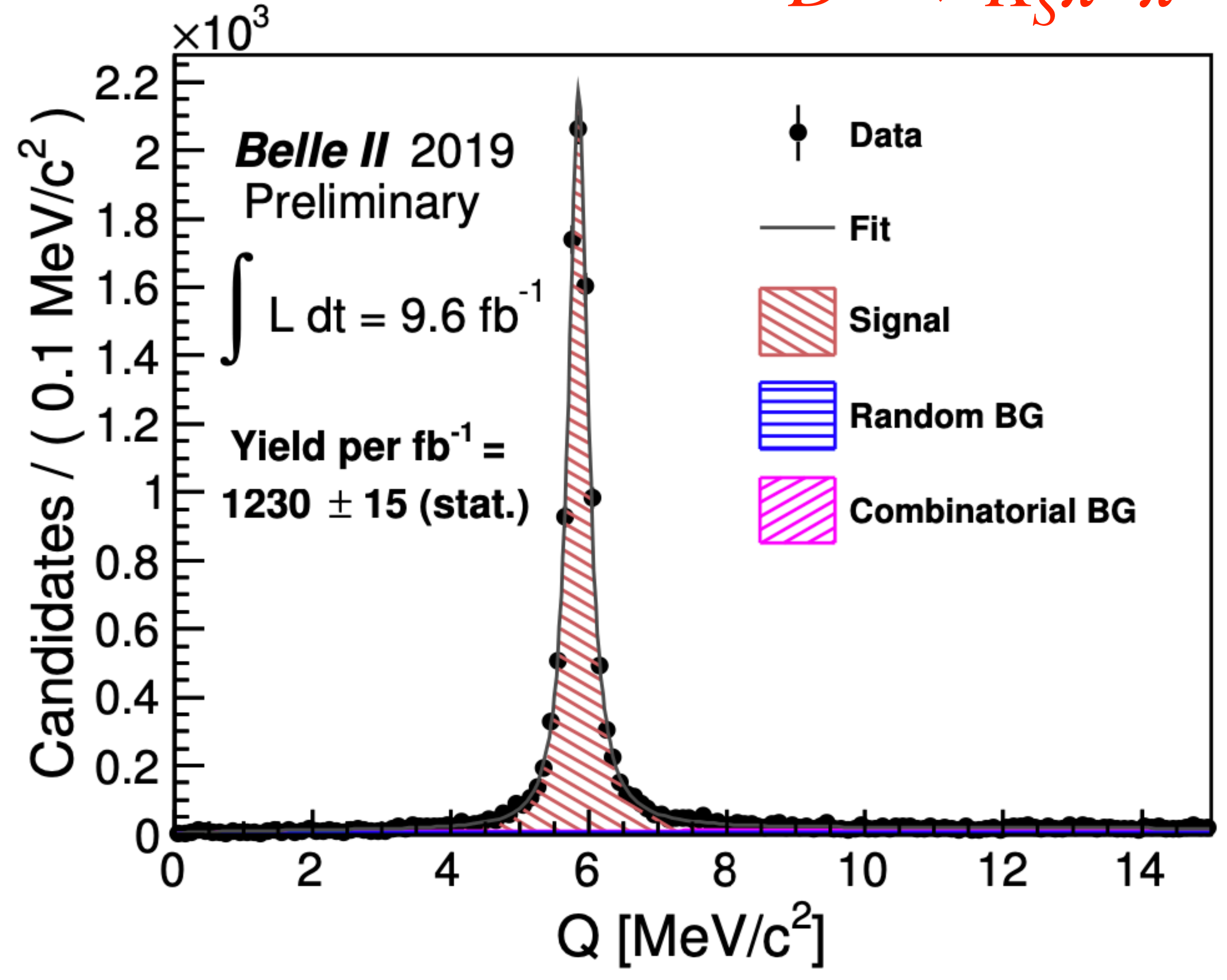
$D^{*+} \to D^0 \pi_s^+$
$D^0 \to K\pi\pi^0$

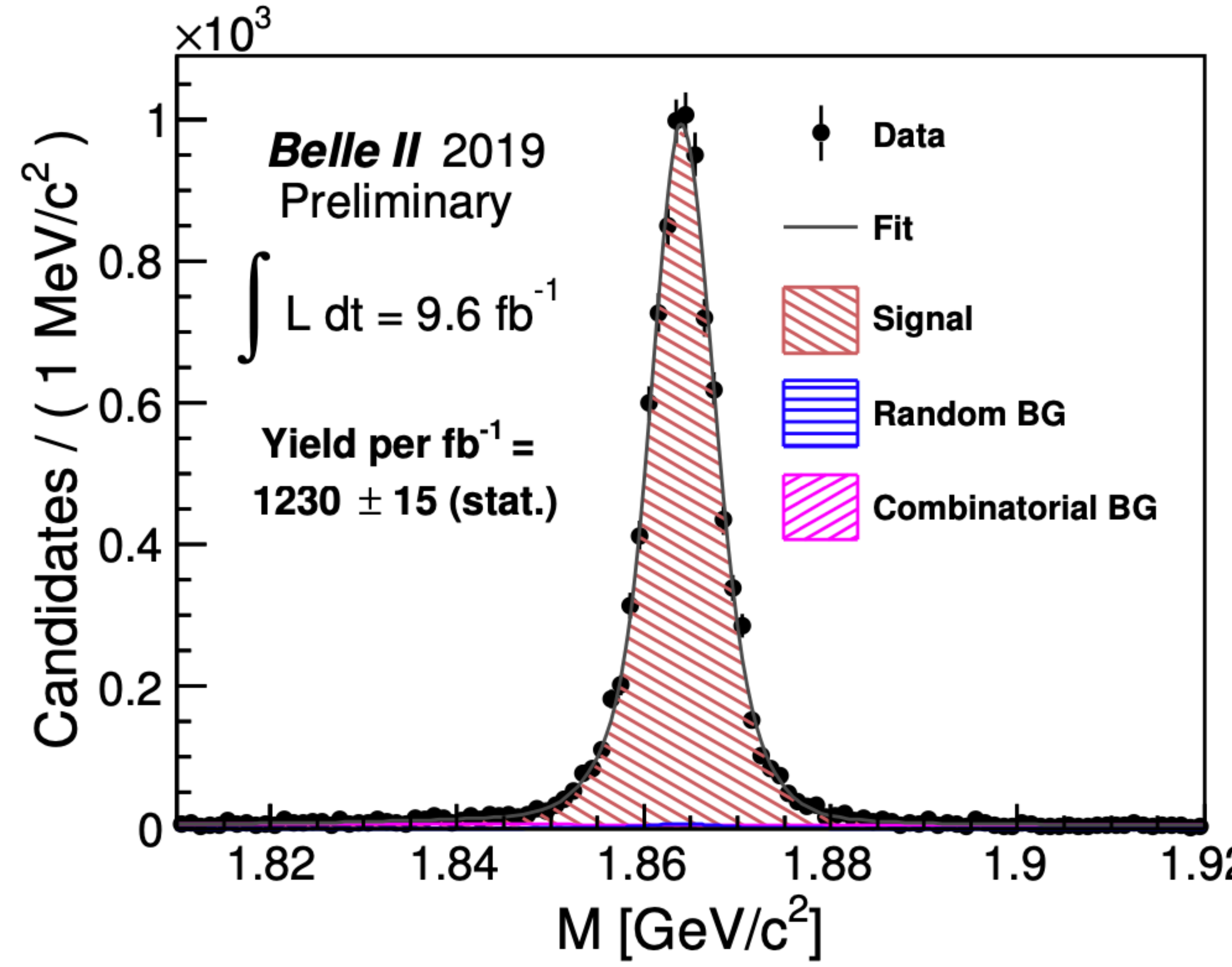
$D^{*+} \to D^0 \pi_s^+$
$D^0 \to K\pi$

$D^0 \to K_S\pi^+\pi^-$ Dalitz Analysis

direct measurement of mixing and CPV parameters

$D^{*+} \to D^0\pi_s^+$
$D^0 \to K_S\pi^+\pi^-$





➡ Time-dependent fit to the Dalitz amplitudes

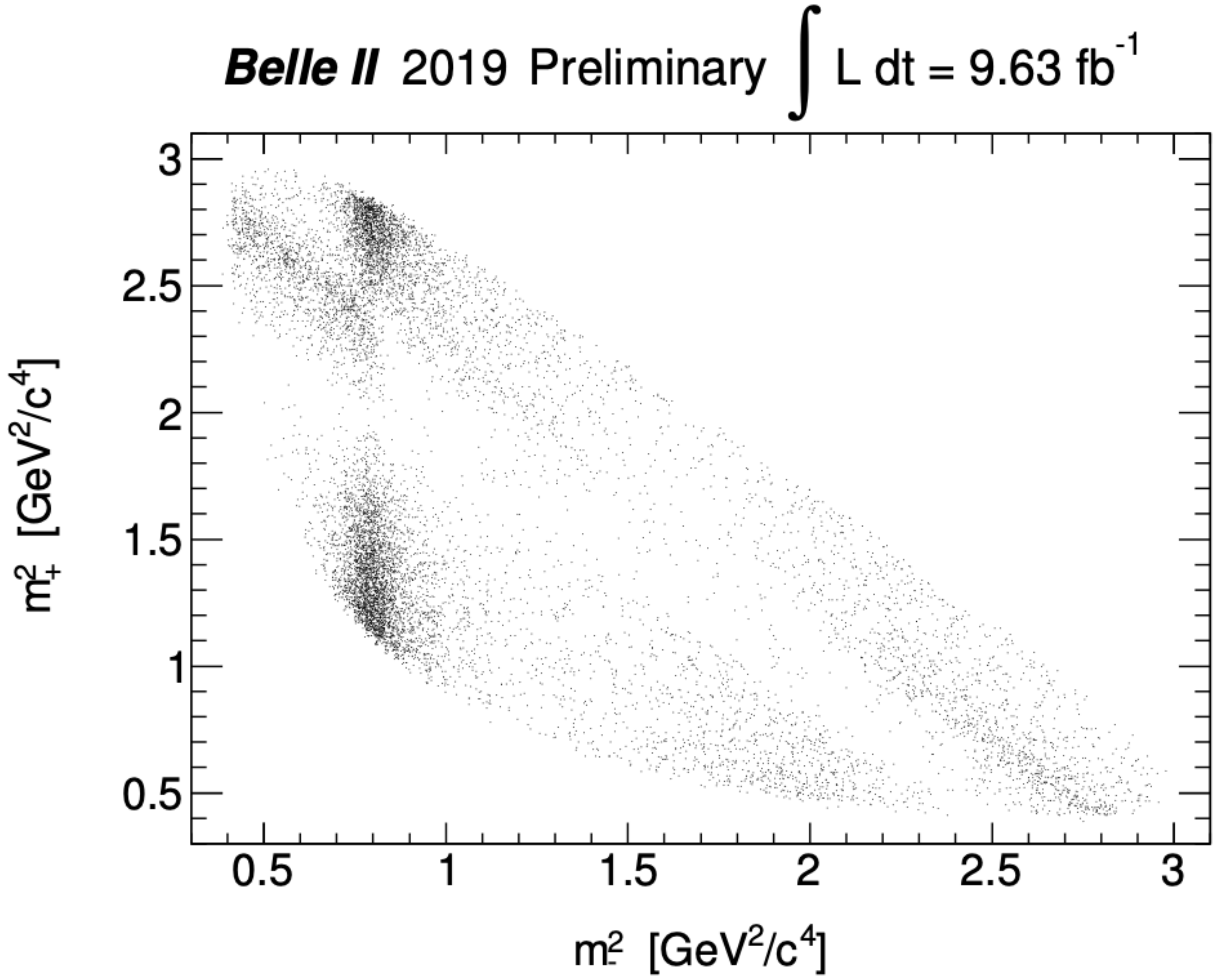
- assuming a Dalitz model, extracting amplitudes and phases from data (→ source of irreducible systematics)
- scaling **errors** from the Belle analysis, ***not*** including improved proper time resolution:

Data	stat.	syst. red.	syst. irred.	Total	stat.	syst. red.	syst. irred.	Total
		x (10^{-2})				y (10^{-2})		
976 fb^{-1}	0.19	0.06	0.11	0.20	0.15	0.06	0.04	0.16
5 ab^{-1}	0.08	0.03	0.11	0.14	0.06	0.03	0.04	0.08
50 ab^{-1}	0.03	0.01	0.11	0.11	0.02	0.01	0.04	0.05
		$\lvert q/p\rvert$ (10^{-2})				ϕ $(^\circ)$		
976 fb^{-1}	15.5	5.2-5.6	7.0-6.7	17.8	10.7	4.4-4.5	3.8-3.7	12.2
5 ab^{-1}	6.9	2.3-2.5	7.0-6.7	9.9-10.1	4.7	1.9-2.0	3.8-3.7	6.3-6.4
50 ab^{-1}	2.2	0.7-0.8	7.0-6.7	7.0-7.4	1.5	0.6	3.8-3.7	4.0-4.2

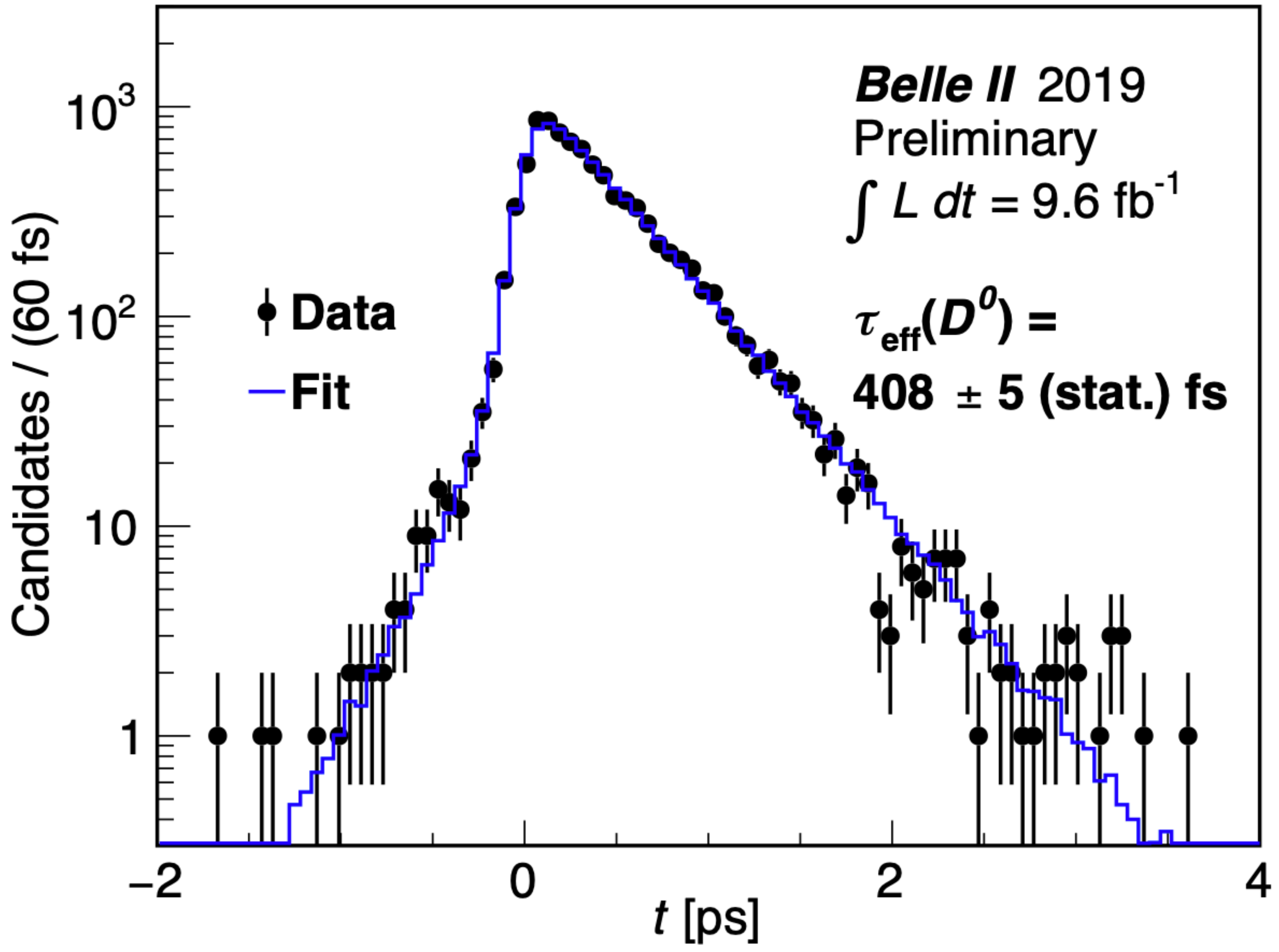
$D^0 \to K_S\pi^+\pi^-$ Decays @ Belle II

reconstruction performance

- ➡ nice Dalitz Plot, visible resonances
- ➡ ongoing sensitivity study for mixing and CPV parameters measurements

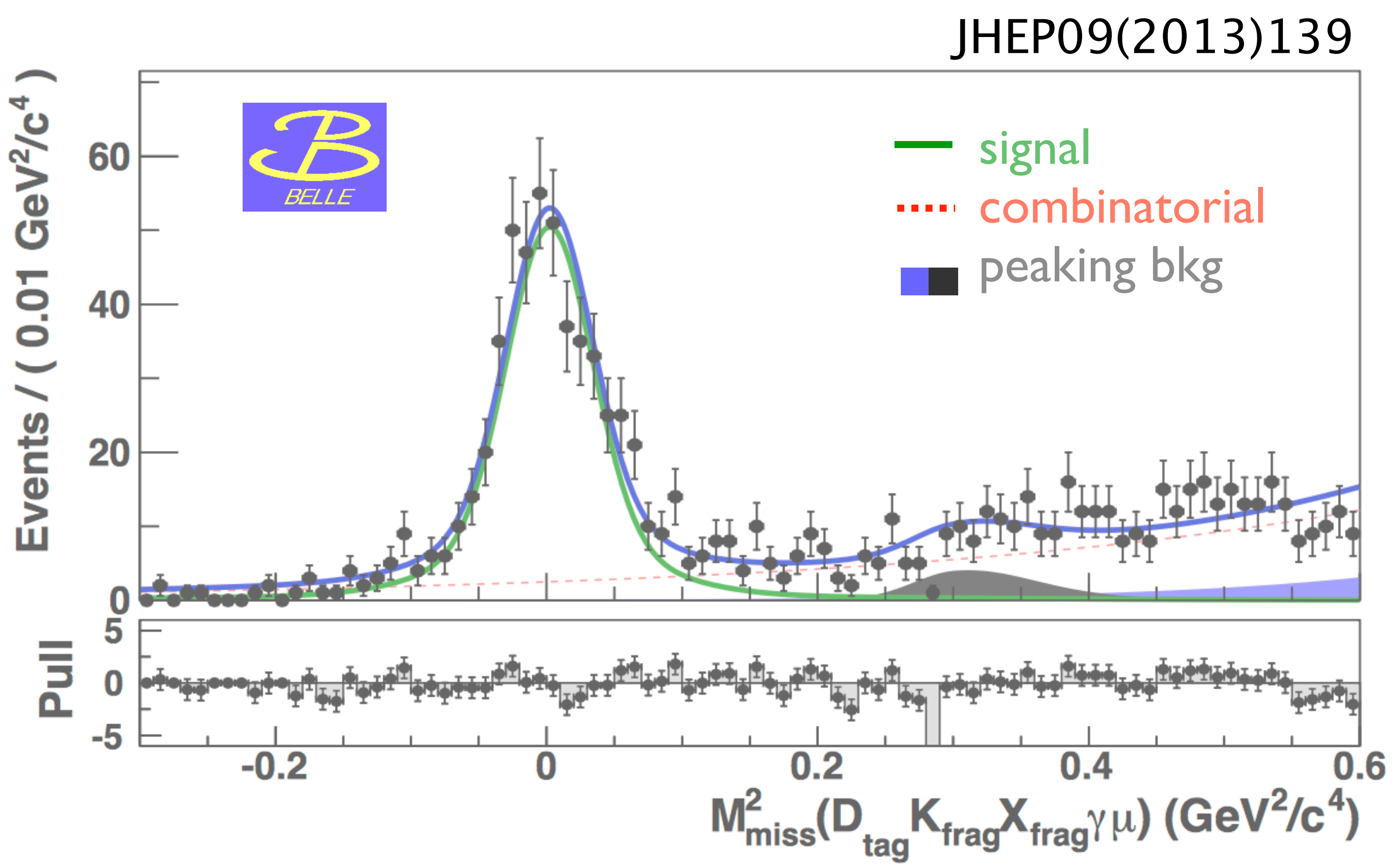


- ➡ extracted lifetime compatible with expected WA, (410.1 ± 1.5) fs
- ➡ proper time resolution comparable to the ones observed in lifetime analysis



Full Charm Event Reconstruction

- (semi-) leptonic decays
- decays to invisible
- inclusive Λ_c sample



➡ **recoil method** successfully exploited for D_s decays:

$$e^+e^- \to c\bar{c} \to D_{\rm tag} X_{\rm frag} D_{\rm sig}$$

light mesons (K, π, …)

reconstructed in several channels (D^0, D^*, D_s, …)

signal channel

➡ use energy and momentum conservation to search for the desired final state:

- *example*: $e^+e^- \to D_{\rm tag} X_{\rm frag} K D_s^{*+}$

  $D_s^{*+} \to D_s^+ \gamma \quad \boldsymbol{D_s^+ \to \mu^+ \nu}$

- "miss" quantities computed for the system:

$$D_{\rm tag} + X_{\rm frag} + K + \gamma + \mu^+$$

- compute the missing mass squared

$$M^2_{\rm miss}(\nu) = (E_{\rm miss} - |\vec{p}_{\rm miss}|)(E_{\rm miss} + |\vec{p}_{\rm miss}|)$$

application/extensions of Full Charm-Event Reconstruction

$D_{(s)}^+ \to \mu^+ \nu$

Belle Analysis

$D_s^+ \to \mu^+\nu$

$e^+e^- \to D_{tag}X_{frag}K\gamma D_s^+$

$D_s^{*+} \to D_s^+\gamma$

➡ Scale *Belle* yields/stat. error to ***50 ab⁻¹***

$D_s^+ \to \mu^+\nu$	
inclusive	exclusive
5.2×10^6	27×10^3

$\delta(|V_{cs}|) = 0.004$,

$\delta(|f_{Ds}|) = 0.9$

- stat. error ~1/3 of the theory error

➡ Same analysis method for the D^+ channel

- *Belle simulation* (5.5 ab⁻¹) scaled to ***50 ab⁻¹***

$D^+ \to \mu^+\nu$	
inclusive	exclusive
3.5×10^6	1250

$\delta(f_d|V_{cd}|) = 1.3$

- competitive with CLEOc and BESIII

Inclusive D^0 Inclusive Λ_c

extension of the Full Charm Event Reconstruction

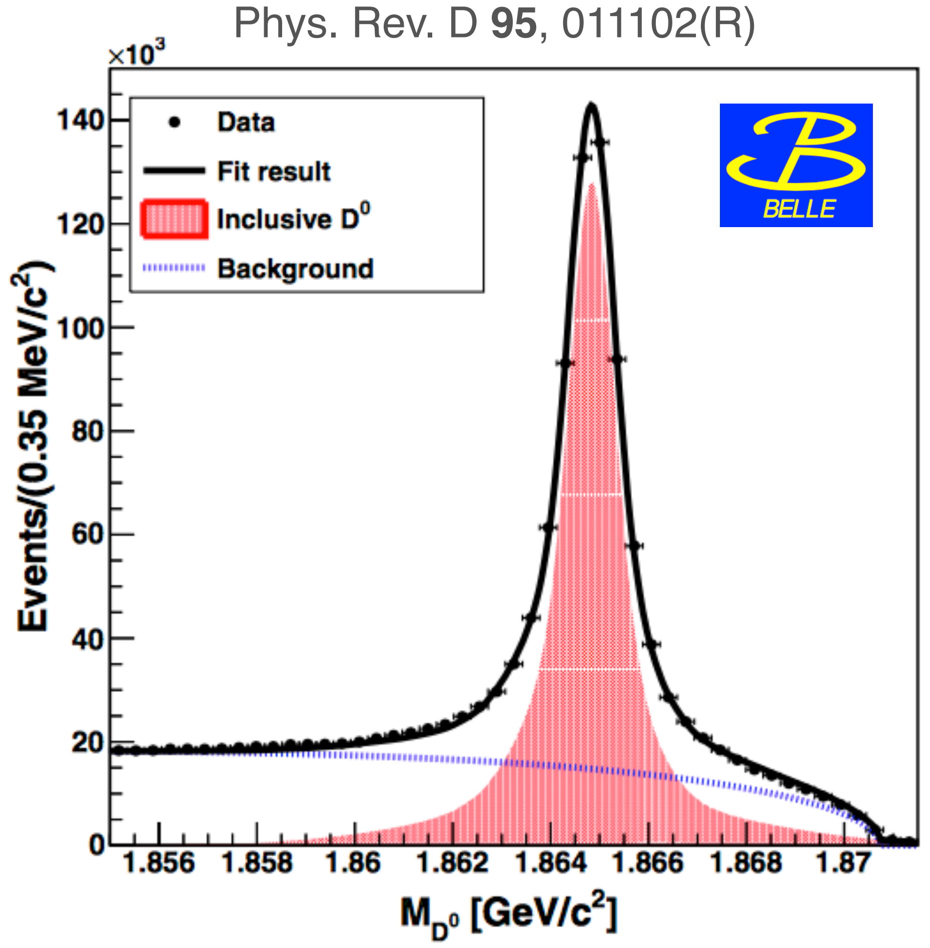
$e^+e^- \to D_{tag}X_{frag}\pi_s^+ D^0$ $D^{*+} \to D^0\pi_s^+$

$M_{miss} = D^0$ mass

Belle Analysis

$D^0 \to \nu\bar{\nu}$

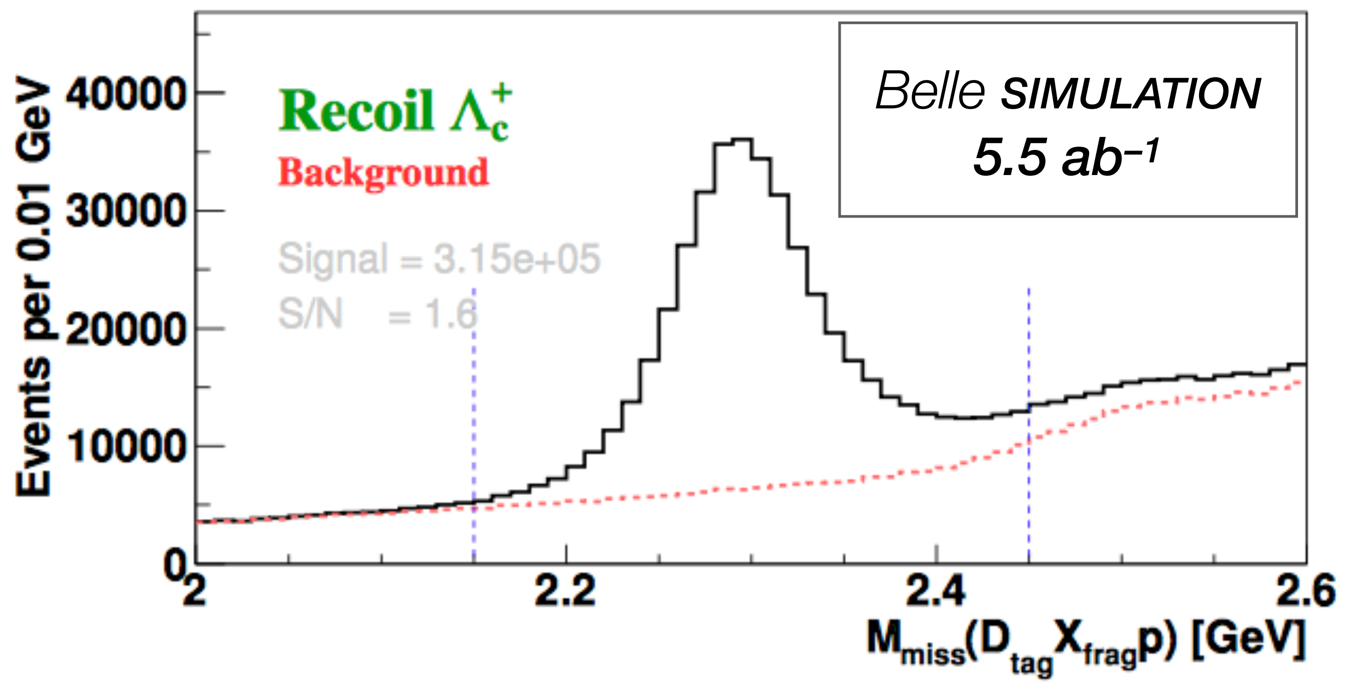
Phys. Rev. D **95**, 011102(R)



➡ **38x10⁶ inclusive D⁰** with 50 ab⁻¹

$e^+e^- \to D_{tag}X_{frag}p\Lambda_c^+$

$M_{miss} = \Lambda_c^+$ mass



➡ **2.8x10⁶ inclusive Λc⁺** with 50 ab⁻¹

Unique samples that allow to:

- measure absolute branching fractions
- study semi-leptonic decays
- search for **rare/forbidden decays** with missing energy

… works for semi-leptonic decays too

Conclusions

and prospects

- ➡ ***Belle II*** potential in many charm sectors is clear on paper (extrapolated from *Belle*), now being confirmed with data
- ➡ Reconstruction performance is improving, in many cases comparable or better (proper time resolution) to *Belle*
- ➡ Stay tuned for many results on charm from ***Belle II*** in the next years!