Charm Working Group Outlook

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First *BelleII* Italian Collaboration Meeting

Rome, 9th ~ 10th June 2014

outline

- ➡ Why Charm Physics @ *BelleII*
- ➡ Charm Analyses and Golden Channels
- ➡ Charm Working Group Mandate and Plan
- ➡ Conclusions

Why Charm Physics?

✓ charm is an *up*-type quark:

- complementary info on Mixing and CPV w.r.t. B and K systems
- constrains NP models probing a different space of parameters

◉ the charm quark is not light (as the strange) neither heavy (as the bottom):

- computation of hadronization processes is hard to make → theoretical predictions (mixing, CPV, …) are affected by large errors preventing straightforward interpretation of measurements
- precision of lattice calculations down to 0.1% expected in 2030

➡ Need to identify theoretically clean observables

➡ Can measurements be used as input for theoretical predictions?

➡ Charm Physics is anyway worth studying and *BelleII* can provide high precision measurements much more difficult to do at LHCb

➡ In case of NP signals seen at LHCb, confirmation from *BelleII* will be absolutely needed (different environment, different systematics, …)

Overview of Charm Analyses

Open Charm

D Mixing, CPV, Rare decays ★

Leptonic & Semileptonic ★
$D_s^* \to \mu\nu$ recently calculated

Dalitz plot analyses

Branching ratios
including $D_{(s)}^*$; all four ground-state baryons

Masses and lifetimes
Masses of interest due to exotics = molecules?
Lifetimes FOCUS-dominated, connect BF (exp't) to Γ_i (theory)

ISR "scan" for charm production

Charmonium

Masses, spin-parity

Hadronic transitions

EM transitions

Fragmentation (e.g., double charmonium)

New decay modes?

Exotics

The X, Y, Z states
Now clear there are many "charmonium-like" states

Mapping out properties J^{PC}, decays, mass, Γ
Searching for related states isospin partners

How do we compare to BESIII?
We have "internal synergy" with bottomonium results where BelleII will presumably dominate…

ISR is a "free scan", and can access states above BESIII maximum (~ 4.6 GeV)

Charm WG convenors:

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Sensitivity on Mixing and Indirect CPV

$D^0 \to K^{(*)-}\ell^+\nu$	492 fb^{-1}	50 ab^{-1}
R_M	$(1.3 \pm 2.2 \pm 2.0) \times 10^{-4}$	$\pm 0.3 \times 10^{-4}$
★ $D^0 \to K^+K^-, \pi^+\pi^-$	976 fb^{-1}	50 ab^{-1}
😁 y_{CP}	$(1.11 \pm 0.22 \pm 0.11)\%$	$\pm 0.04\%$
😐 A_Γ	$(-0.03 \pm 0.20 \pm 0.08)\%$	$\pm 0.03\%$
★ $D^0 \to K^+\pi^-$	400 fb^{-1}	50 ab^{-1}
😁 x'^2	$(1.8 \pm 2.2 \pm 1.1) \times 10^{-4}$	$\pm 0.22 \times 10^{-4}$
😁 y'	$(0.06 \pm 0.40 \pm 0.20)\%$	$\pm 0.04\%$
A_M	0.67 ± 1.20	± 0.11
$\lvert\phi\rvert$	0.16 ± 0.44	± 0.04
★ $D^0 \to K^0_s\pi^+\pi^-$	921 fb^{-1}	50 ab^{-1}
x	$(0.56 \pm 0.19 \pm 0.06 \pm 0.08)\%$	$\pm 0.08\%$
y	$(0.30 \pm 0.15 \pm 0.06 \pm 0.04)\%$	$\pm 0.05\%$
$\lvert q/p\rvert$	$0.90 \pm 0.16 \pm 0.04 \pm 0.06$	± 0.06
ϕ	$-0.10 \pm 0.19 \pm 0.04 \pm 0.07$	± 0.07

Note: straightforward extrapolation from Belle:

$$\sigma_{BelleII} = \sqrt{(\sigma^2_{stat} + \sigma^2_{sys})\frac{\mathcal{L}_{Belle}}{50\ \mathrm{ab}^{-1}} + \sigma^2_{\mathrm{ired}}}$$

→ take with care

★ golden
😁 competitive with LHCb
😐 not competitive with LHCb

in 2023:
Belle II 50 ab^{-1}
vs
LHCb 23 fb^{-1}

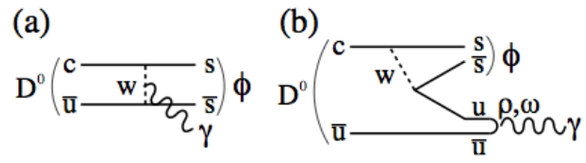
Sensitivities for Direct CPV

mode	$\mathcal{L}$ (fb^{-1})	A_{CP} (%)	Belle II at 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
$D^0 \to \pi^0\pi^0$	976	$\sim \pm 0.60$	± 0.08
$D^0 \to K^0_S\pi^0$	791	$-0.28 \pm 0.19 \pm 0.10$	± 0.03
$D^0 \to K^0_S\eta$	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
$D^+ \to \eta\pi^+$	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	$-0.36 \pm 0.09 \pm 0.07$	± 0.03
$D^+ \to K^0_SK^+$	977	$-0.25 \pm 0.28 \pm 0.14$	± 0.05
$D^+_s \to K^0_S\pi^+$	673	$+5.45 \pm 2.50 \pm 0.33$	± 0.29
$D^+_s \to K^0_SK^+$	673	$+0.12 \pm 0.36 \pm 0.22$	± 0.05

- Measurement of single asymmetries is favourited at *Belle II* since initial state is symmetric (c-cbar vs p-p)
- Channels with *neutrals* (γ, π^0) easier at *Belle II* (shaded regions)
- LHCb can still be competitive in some channels, and it's more precise on ΔA_{CP}

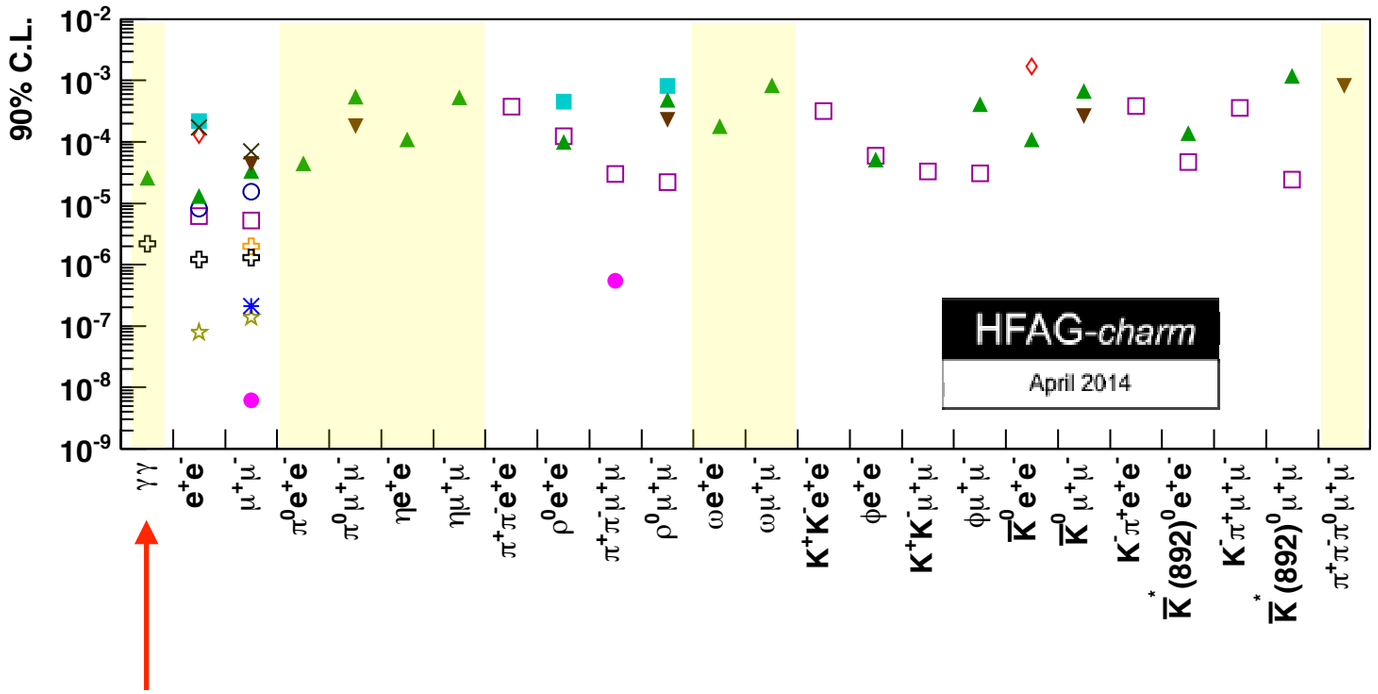
- Modes with K_S: $K^0/\bar{K}^0$ different interaction with matter → 0.02% irreducible systematics
- Direct CPV sensitivity may reach something in 10^{-5} in some cases!

Direct CPV in $D^0 \to \phi\gamma, \rho^0\gamma$

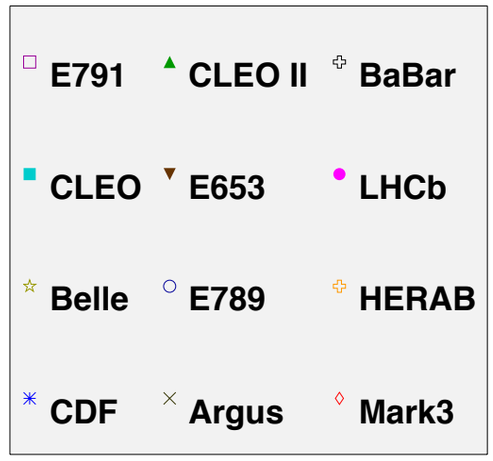


- Direct CPV in radiative decays can be enhanced to exceed 1% (G. Isidori and J. F. Kamenik, PRL 109, 171801 (2012))
  - $D^0 \to \phi\gamma$: A_{CP} up to 2%
  - $D^0 \to \rho^0\gamma$: A_{CP} up to 10%
- $D^0 \to \phi\gamma$: first observation by Belle with 78 fb^{-1} (PRL 92, 101803 (2004))
  - measured yield: $27.6^{+7.4+0.5}_{-6.5-1.0}$
    ⇒ relative error on yield 25% (as would be the error on A_{CP})
- A_{CP} sensitivity at 50 ab^{-1}: ≈ 1%

Rare/Forbidden Decays

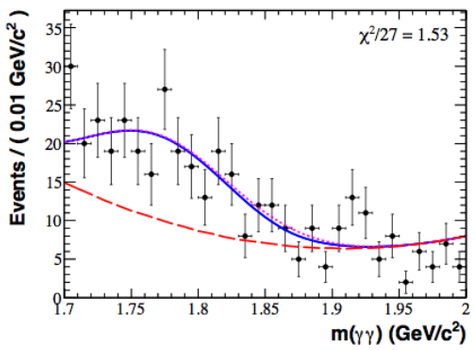


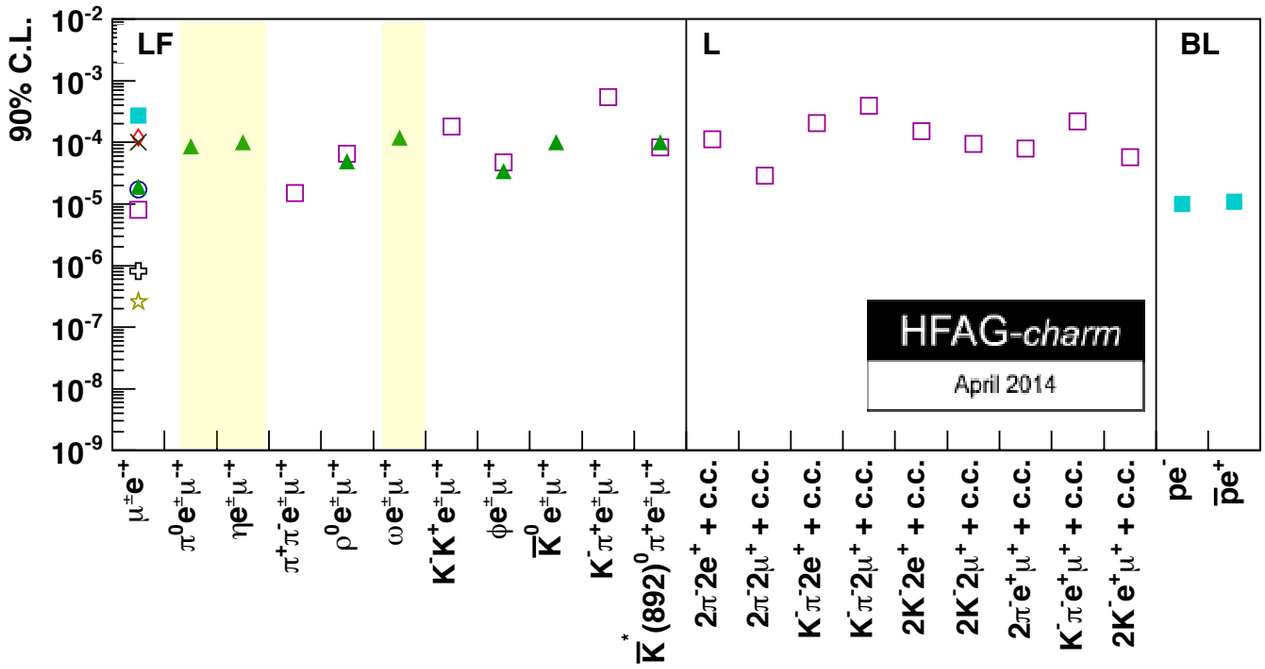
- ➡ Channels with *neutrals* (γ, π^0)
- easier at *Belle II* (shaded regions)
- ➡ *Belle II* can improve these UL by several orders of magnitude



$D^0 \to \gamma\gamma$

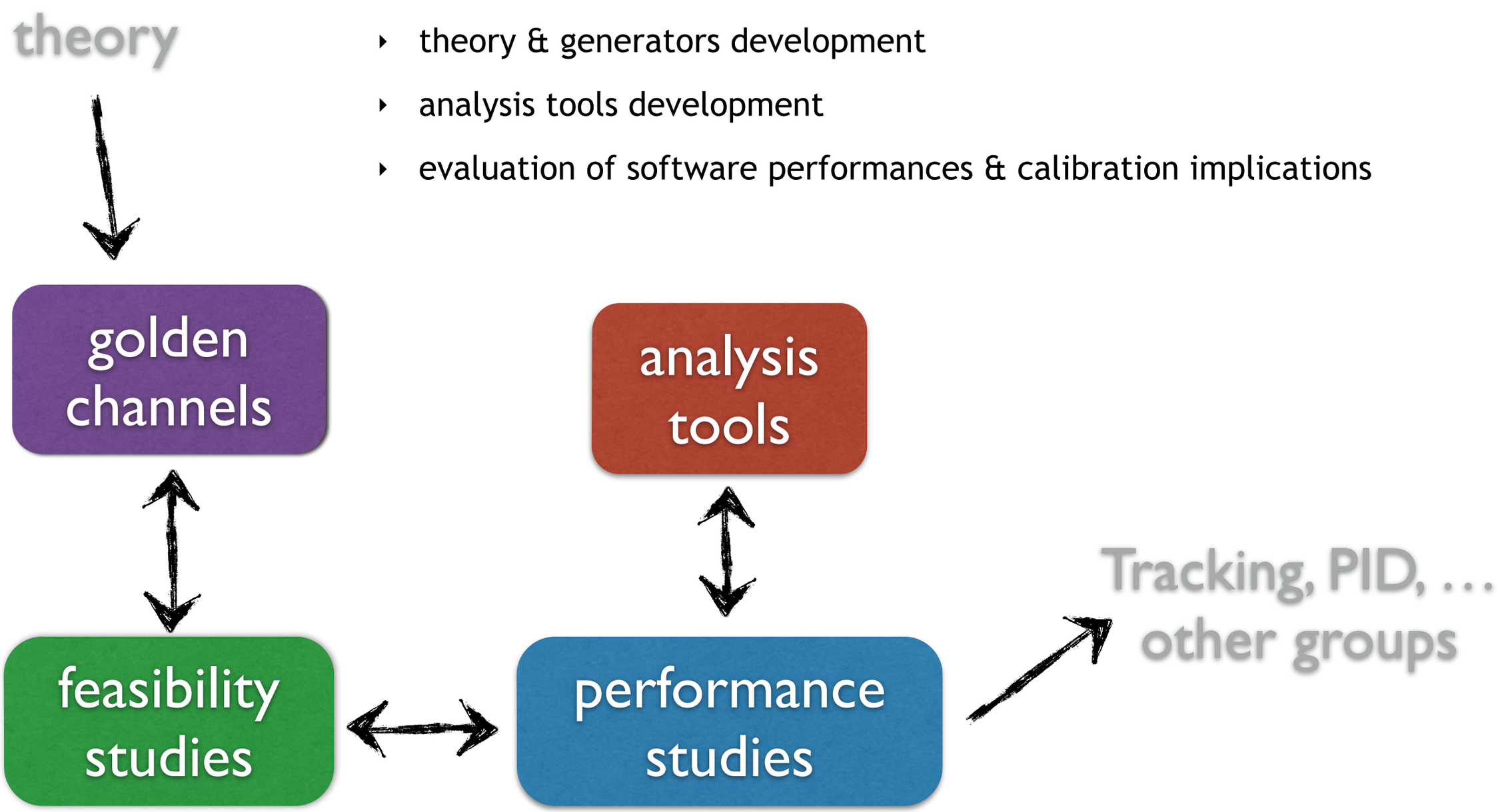
- SM predictions: long distance effects dominate
  $Br \sim \text{few} \times 10^{-8}$
- BaBar, 470 fb^{-1} PRD 85 (2012) 091107
  $Br < 2.2 \times 10^{-6}$ @ 90% CL
- Belle II at 50 fb^{-1}:
  → depends how background behaves
  - if UL would scale with $\mathcal{L}$:
    UL $\sim 2 \times 10^{-8}$
  - if UL would scale with $\sqrt{\mathcal{L}}$:
    UL $\sim 2 \times 10^{-7}$





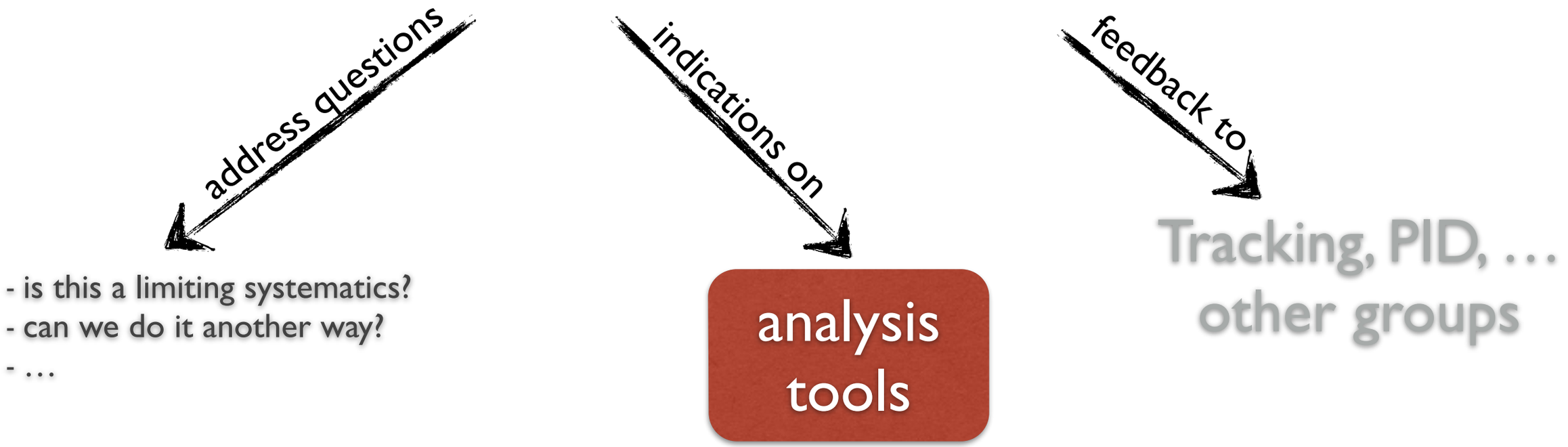
Working Group Mandate

- At this stage of the experiment the WG is expected to:
  - perform feasibility studies
  - theory & generators development
  - analysis tools development
  - evaluation of software performances & calibration implications



Example of Possible Initial Studies

- 20 fb^{-1} continuum MC & dedicated $D^{*+} \to D^0 \pi^+$, $D^0 \to K^+ \pi^-$ are available
- ➡ K_S reconstruction efficiency
- ➡ Neutrals reconstruction efficiency (direct CPV & Rare decays)
  - ‣ γ, π^0, ω, η
- ➡ D^0 tagging (CPV)
  - ‣ soft pion reconstruction & charge mis-ID (CPV)
    - ‣ is it worth using D from B decays?
- ➡ neutrino missing energy reconstruction ((semi)leptonic decays



One Slide on the Status of Analysis Tools

- Some tools already available in the analysis package

https://belle2.cc.kek.jp/~twiki/bin/view/Physics/AnalysisSoftware

  - particle selection & combinations
  - vertex fits
  - output to flat ntuples

- Missing tools & classes:

  - the class holding the IP has yet to be designed (time-dependent studies are presently not possible)
  - vertex class that stores the complete information of a vertex fit, including lorentz vectors of daughters after the fit
  - …

Lots of other things to do

Overview & feasibility studies

- Identification of the main physics program
- Feasibility studies (obviously): to lead (and/or develop) the Belle II simulation based sensitivity studies in the respective golden modes
- Systematics uncertainties: develop strategies for mitigating any potentially dominant systematic uncertainties

Generators

- Preparation of signal MC: decay files, generators, fragmentation settings, new particles etc., and where relevant, collaborate with theorists to implement new generators and settings
- Maintenance of the Belle II evtgen DECAY.DEC section relevant to the group

Analysis tools

- Co-development of the key reconstruction tools and the respective calibration techniques
- Test the impact of nominal triggers, and develop and test the skimming approach for the analyses in the group. *In Belle II, we will skim mDST data sets in central production, to produce reduced data sets with analysis object content. The data model must be tested for each group.*
- Development of specific analysis tools for physics interpretation

Software Performance & Calibration implications

- Provide feedback on the performance of the simulation and reconstruction tools to your analysis. Perform regular regression tests of the analysis performance.
- Determine the impact of nominal calibration methods, including alignment, on analysis sensitivities.

Planning for the (Early) Summer

tomorrow

B2TIP workshop 16-17 June

B2GM 18-21 June

- ➡ python script to start doing *something* with charm physics (plug your module & play)
  - e.g. soft pion reconstruction efficiency analysis module
- ➡ create the Charm WG twiki page
- ➡ golden channels and golden observables review
- ➡ begin of discussion on data model & (charm-oriented) analysis tools
  - list of priorities
- ➡ initial studies presented in the slide 9

Conclusions

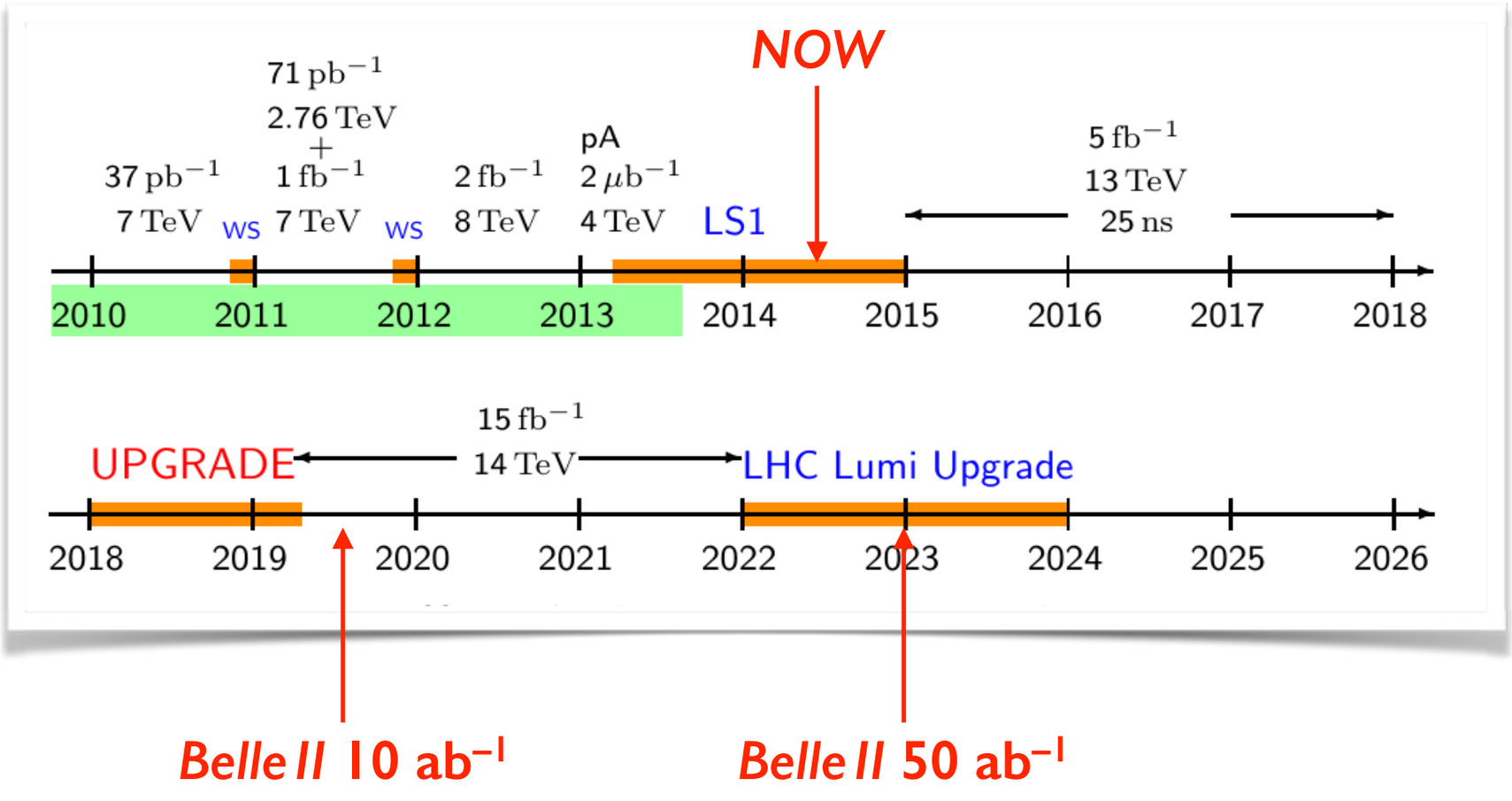
- Rich Charm Physics programme at *BelleII*
  - neutrals in final state (A_{CP}, rare decays), mixing parameters, …
  - and many other things!
- It's time to start *thinking* what is needed to perform such measurements and *develop* it!
- During *BelleII* Theory Interface Platform (B2TIP) workshop we will receive an input/update from theorists on *golden channels* and *golden observables* to be measured at *BelleII*
- During next B2GM we will seriously start the working group activities, we need new ideas & new people (detector-related studies from detector-related people are also very welcome)

backup slides

LHCb vs *Belle II* Schedule

A. Contu for LHCb, Charm2013:

- *expect 8 fb^{-1} by 2018*
- *upgrade 2018-mid 2019 with x3-4 increase in D meson yields*
- *15 fb $^{-1}$ by 2022*



Experiment	L_{int} (stimata al 2020)	σ_{ccbar}	ε_{rec}	$N(D^0 \to K^-\pi^+)$
LHCb	10 fb^{-1}	1.8 mb	2%	9×10^9
BELLE II	36 ab^{-1}	1.3 nb	50%	6×10^8
BES III	20 fb-1	3.6 nb (D^0D^0bar)	50%	1.4×10^6

Overview & feasibility studies

- Identification of the main physics program: although seemingly redundant the landscape is always changing. One must clarify the measurement roadmap and update the golden modes (in conjunction with physics coordinators). This builds on the "Physics of a Super B-factory", and its brief interim update to be released before the next DetectorTriggerB2GM.
- Feasibility studies (obviously): to lead (and/or develop) the Belle II simulation based sensitivity studies in the respective golden modes. One of the biggest issues will be the impact of much larger background on missing energy analyses: tracking should be more realistic in the coming 6 months to allow such studies. To follow the analysis through the full data flow chain (technical exercises).
- Systematics uncertainties: develop strategies for mitigating any potentially dominant systematic uncertainties such as full reconstruction normalisation, ECL resolution, beam background and track vetoes etc.. Its useful to have a perpendicular view/input on the performance group work for systematics.

Theory & generators

- Theory liaison, e.g. for Vub, Vcb, B->K nu nubar, B-> tau/l nu etc. measurements. There is building interest from the theory community to start up a working group in 2014 for preparing a joint yellow report on the physics outlook of Belle II. There will be regular workshops for this joint activity, for which input would be sought from the Belle II physics groups.
- Preparation of signal MC: decay files, generators, fragmentation settings, new particles etc., and where relevant, collaborate with theorists to implement new generators and settings.
- Maintenance of the Belle II evtgen DECAY.DEC section relevant to the group.

Analysis tools

- Co-development of the key reconstruction tools and the respective calibration techniques. For example (non-exhaustive list):
  - full- and semileptonic- tagging approaches will need to be developed, optimised, and the calibration procedure: Semileptonic & Missing E, and EWP groups.
  - Continuum suppression and flavour tagging: TCPV and Hadronic decay groups.
  - Tag vertex fitters: TCPV.
  - Rest-of event tool, with tuning of extra energy and extra track criteria: Missing energy and EWP groups.
- Test the impact of nominal triggers, and develop and test the skimming approach for the analyses in the group. In Belle II, we will skim mDST data sets in central production, to produce reduced data sets with analysis object content. The data model must be tested for each group.
- Development of specific analysis tools for physics interpretation e.g. global fitters for interpreting new phenomena in semileptonic decays.

Software Performance & Calibration implications

- Provide feedback on the performance of the simulation and reconstruction tools to your analysis. Perform regular regression tests of the analysis performance.
- Determine the impact of nominal calibration methods, including alignment, on analysis sensitivities. In particular we need to determine the most optimal, fast calibration sequence that has minimal impact on analysis.