Status of Upgrade performance studies

Ale Gaz

2nd General VTX Workshop

April 21st 2026

Ongoing activities

- Tracking detectors:
  - 5-layer VTX;
  - CDC: design a new detector, the oDC (“o”= outer), replacing SL2-8 of the current CDC;
  - open question: what to put between the oDC and the VTX:
    1) iDC (“i” = inner);
    2) STL: 1 or 2 layers of silicon strips (tracking only capabilities);
    3) FTL: 1 layer of silicon detectors with TOF capabilities (tracking + PID);
    4) 1 layer of STL and 1 layer of FTL (?)
- PID detectors: work on sensors and electronics to keep the current performance;
- ECL: new and faster electronics, better time resolution and background rejection;
- KLM: focus on running RPC’s in proportional mode and keep studying the impact of TOF capabilities;
- Forward taggers: studying opportunities for physics channels in the very forward direction.

Outline of today's talk

1) Non tracking-related studies;

2) Tracking related studies;

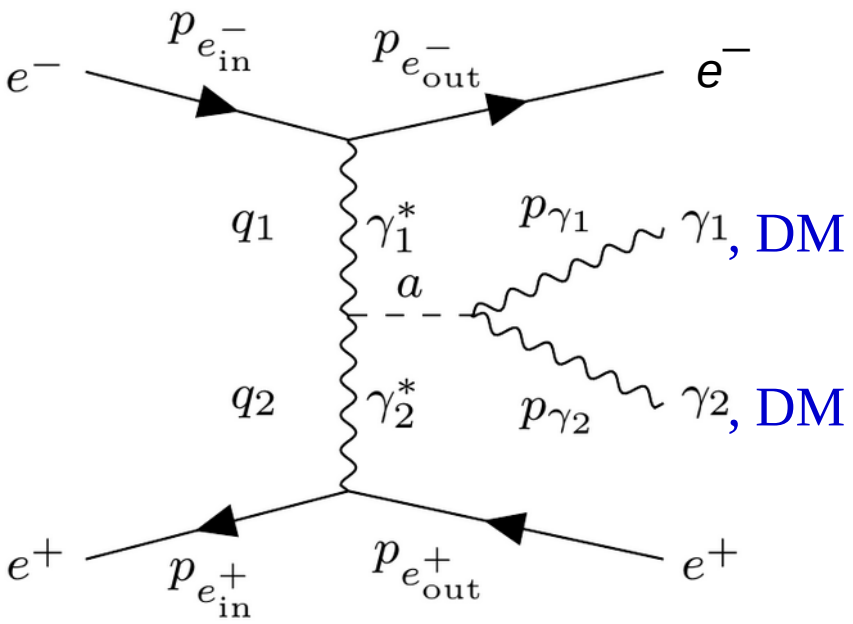
3) Acceptance / boost;

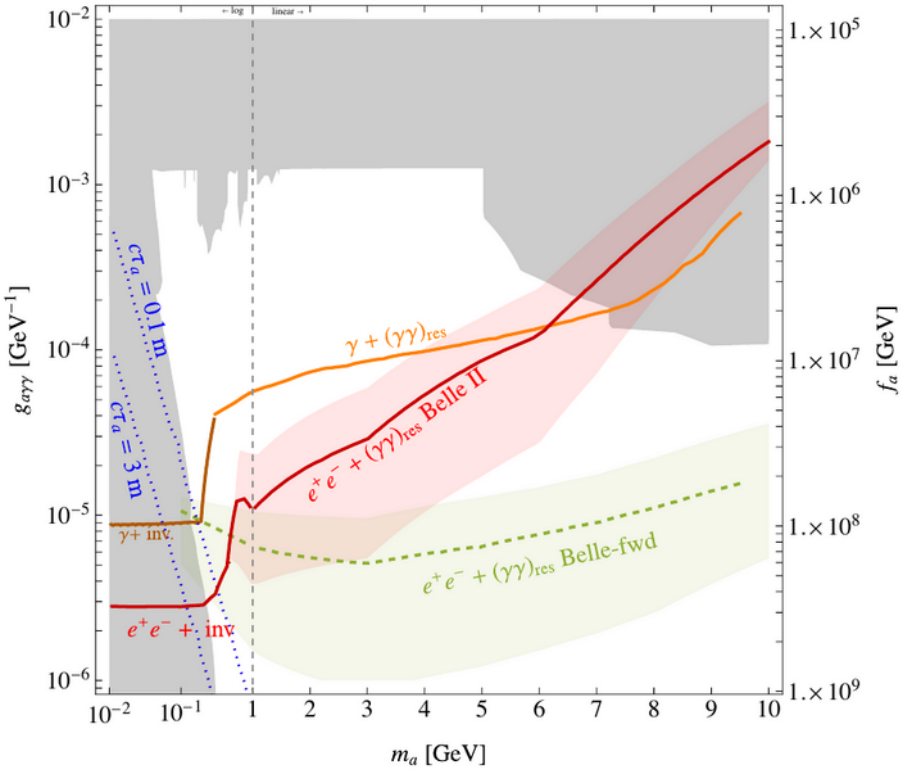
4) Outlook.

1) Non tracking related studies

Forward taggers

- Inspired by F. Acanfora, R. Franceschini, A. Mastroddi, and D. Redigolo works arXiv:2406.14614 [hep-ph] and arXiv:2307.06369 [hep-ph];

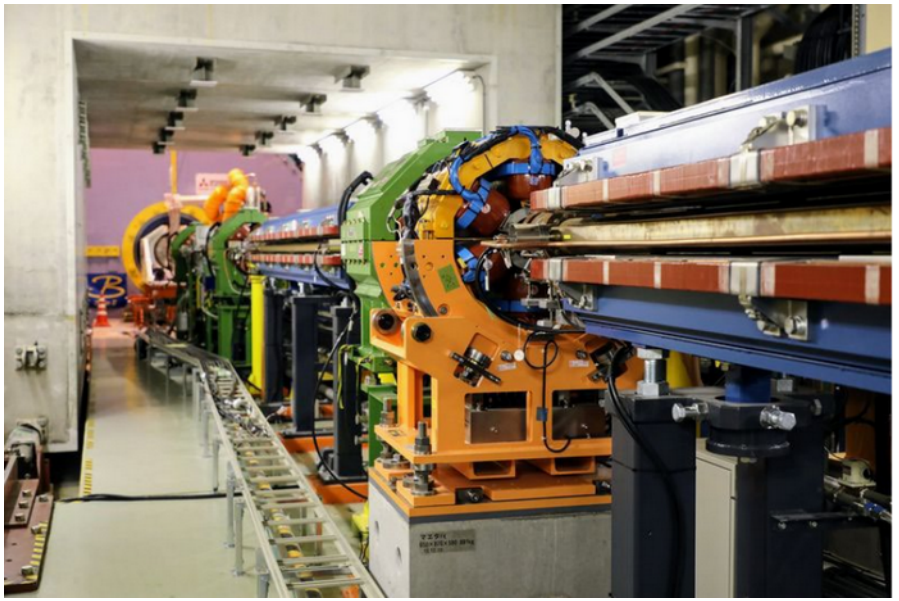


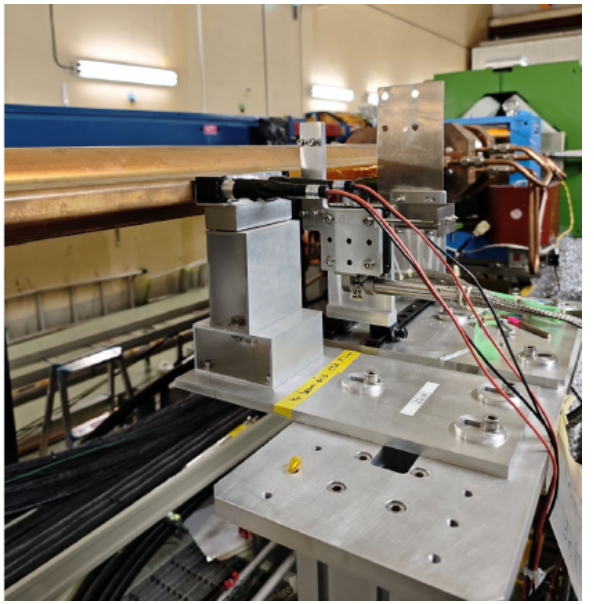


- Improving the coverage on the forward region might boost Belle II sensitivity to a → γγ, (a → invisible), true muonium, …

Forward taggers – the challenges

- Considering the installation of detectors (scintillators + SiPM ?) near the accelerator dipoles;

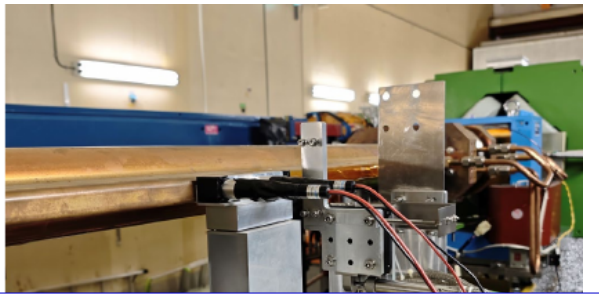




- Challenges / homework:
  - need to consider detector and accelerator material;
  - mandatory to take into account beam optics and simulation;
  - backgrounds (radiative Bhabha, …) will be very severe (a → invisible ~hopeless?);
- Very ambitious project, **but reward might be high**: need careful scrutiny.

Forward taggers – the challenges

- Considering the installation of detectors (scintillators + SiPM ?) near the accelerator dipoles;



For more information / details:

➔ on Dec 17th 2025 we had an entire UWG meeting dedicated to this topic;

➔ there will soon be a workshop organized by XiaoLong.

  - ➔ need to consider detector and accelerator material;
  - ➔ mandatory to take into account beam optics and simulation;
  - ➔ backgrounds (radiative Bhabha, …) will be very severe (a → invisible ~hopeless?);
- Very ambitious project, **but reward might be high**: need careful scrutiny.

KLM: RPC in proportional mode

See presentaton by Antonio on April 8th

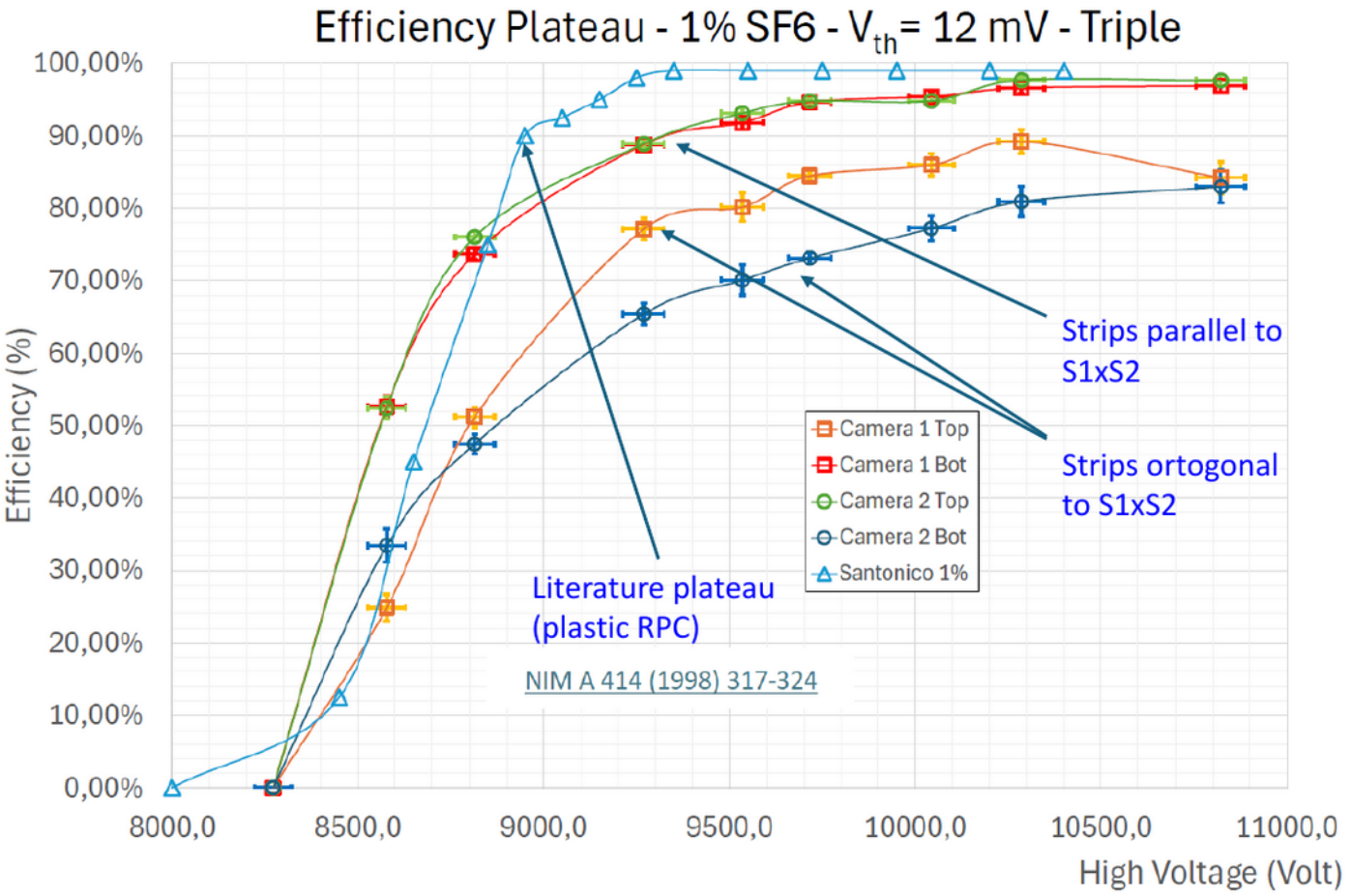
Plateau at 1% SF6

- triple coincidence: S1xS1x other RPC

- 12 mV threshold
- 50 ns gate after scintillator trigger

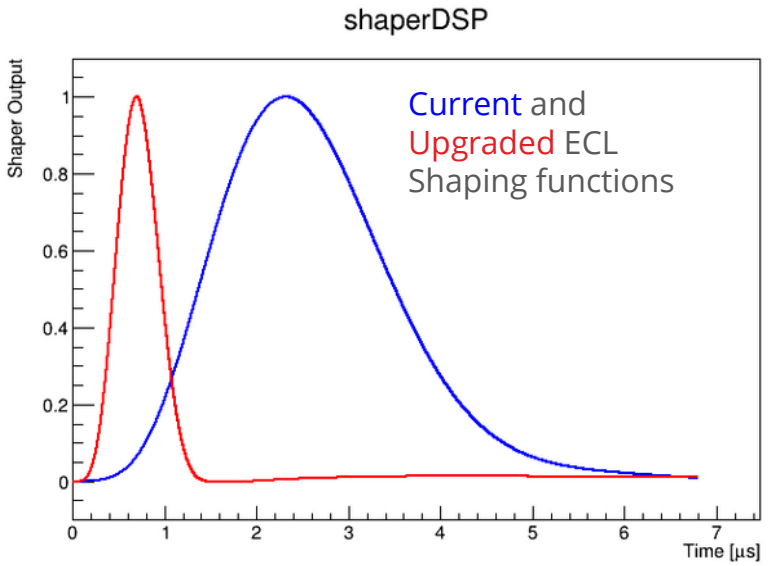
Slower rise than plastic RPC in literature

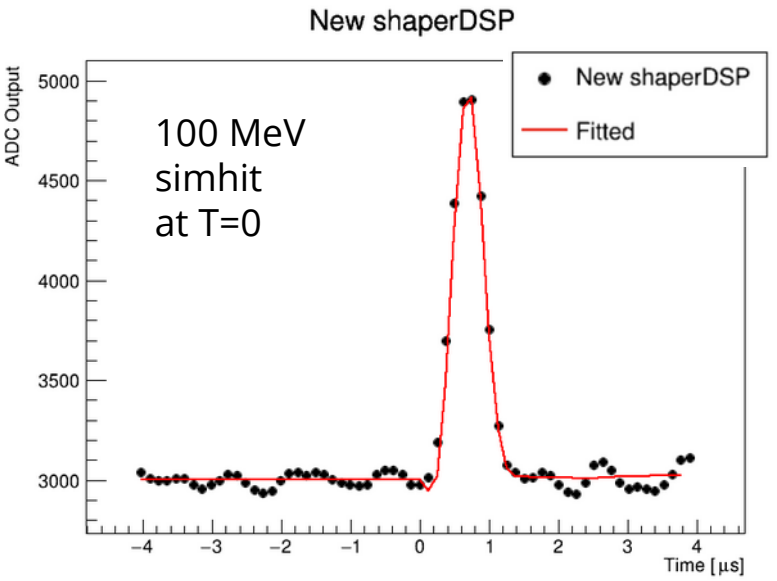
NB: Data (HV values) rescaled to
P =1010 hPa
T = 293 °K
According to $V=V_{set}*P_0/P*T/T_0$



ECL studies

- Working on faster electronics, reducing the shaping time from 500 ns to 150 ns;
- Goal: improve background reduction and reduce sensitivity on background conditions affecting γ's and π^0's;
- Integration in basf2 about to be completed;
- Study the impact on performance in:
  - ➔ particle gun γ's and π^0's;
  - ➔ some key physics channels;
- No need to implement a new geometry.





2) Tracking related studies

FTL

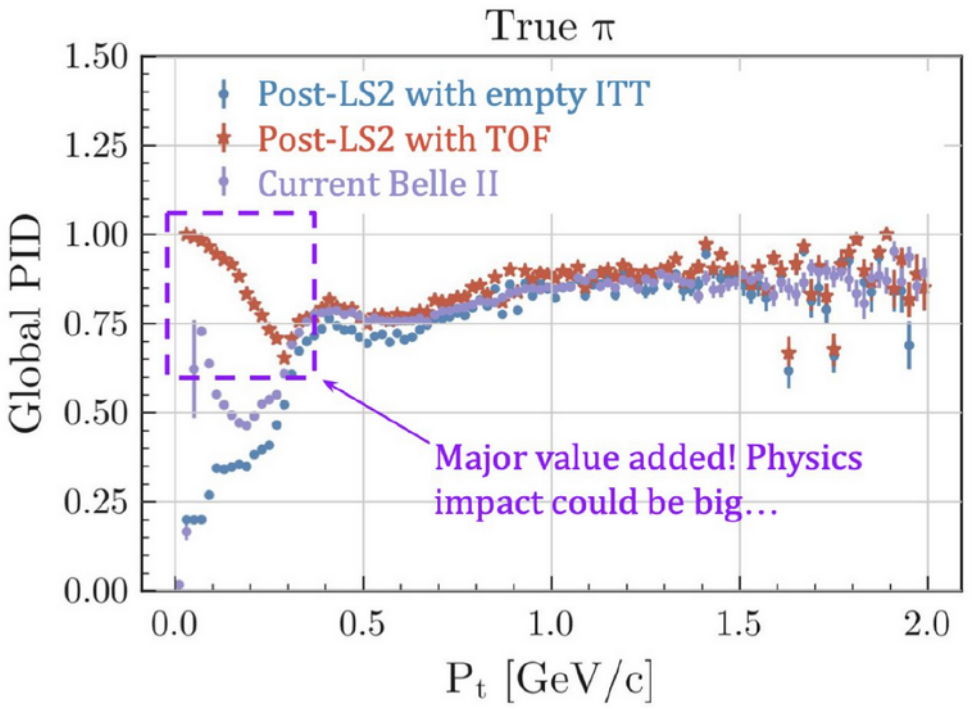
- FTL = Fast Timing Layer;
- If we do not proceed with the iDC, we create a ~20 cm gap between the VTX and the oDC;
- On top of that with the replacement of the SVD with a pixel detector and the loss of the two innermost superlayers of the CDC, we lose any PID information for tracks with p_T < ~150 MeV/c;

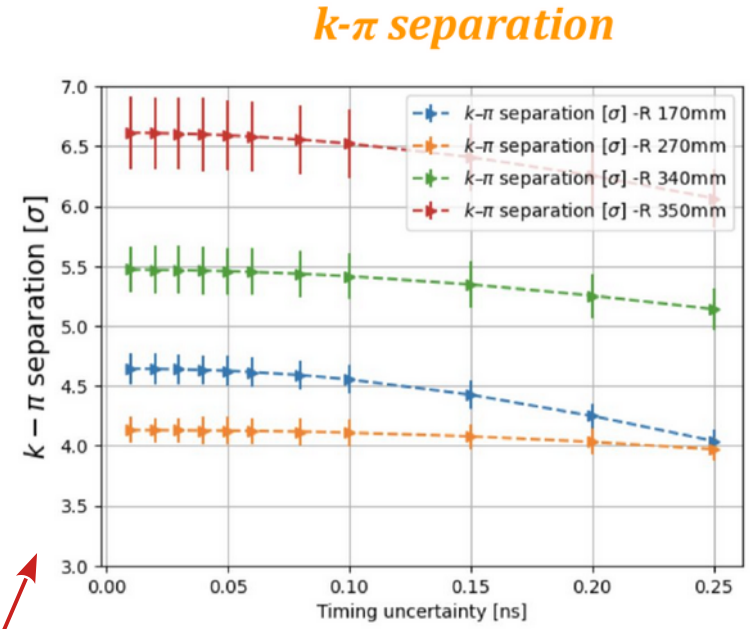
- Idea: instrument the gap with silicon detectors (LGAD's) with TOF capabilities in order to:
  - ➔ add one extra point for tracking;
  - ➔ get PID information for low-momentum tracks.

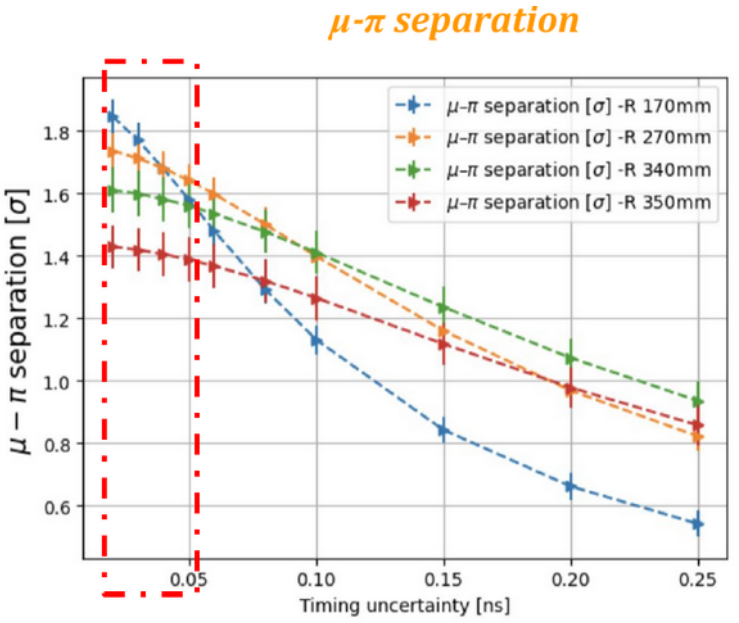
Yubo Han

FTL

- Real bonus of this technology: measurement of TOF;
- Require resolution of ~50ps;



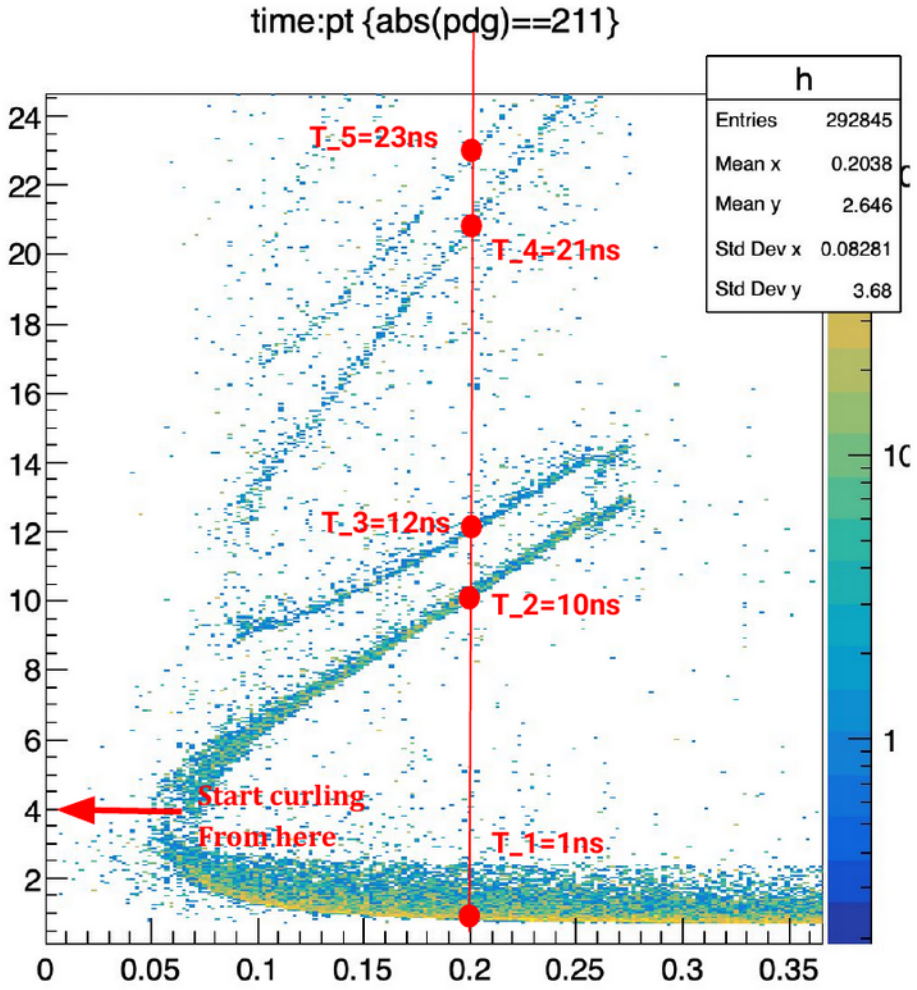




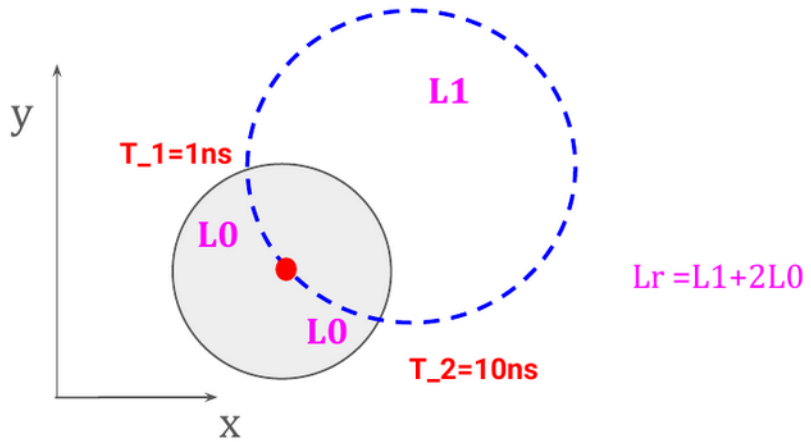
Separation power for 100 MeV/c tracks

FTL

- New idea: exploit loopers to improve PID and event t0 measurement, see Yubo's presentation;



- TOF = L * sqrt(p^2 + m^2)/cp
- Looking at pions with pt == 0.2 GeV/c
- Assuming p is constant: TOF will be related to L only



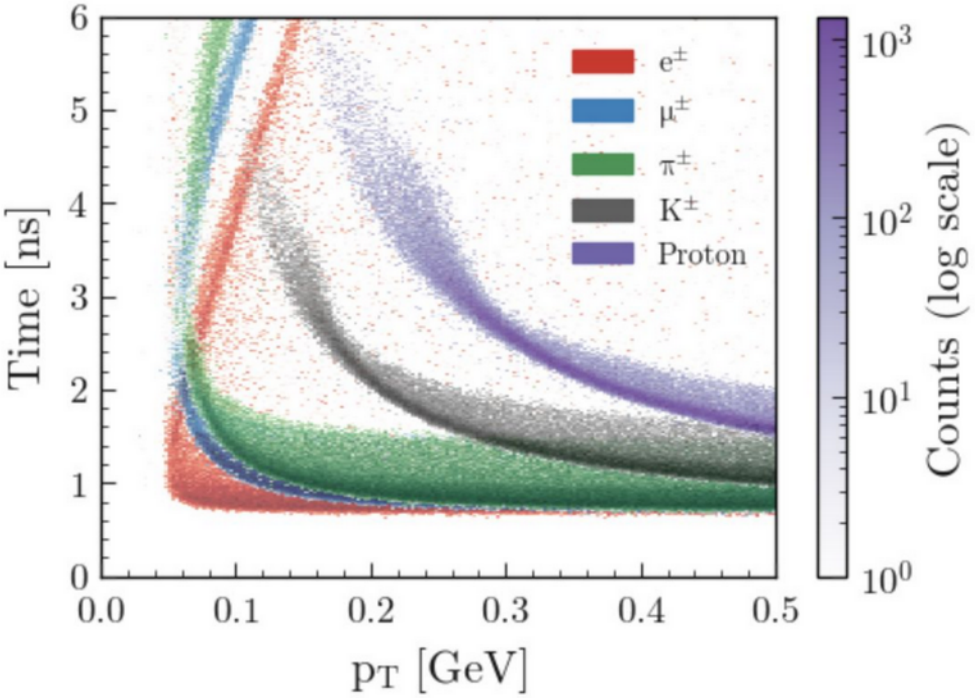
T_1: L0
T_2: L0+L1
T_3: L0+L1+2L0 = L0+Lr
T_4: L0+L1+2L0 +L1=L0+L1+Lr
T_5: L0+L1+2L0 +L1 + 2L0 = L0+2Lr

FTL

Yubo Han

loopers carry **extra timing and path-length information** that can be turned into useful observables.

- Improve low-pt PID
- Clean eventT0 determination
  - From same particle
  - Repeated time stamps with known period
    - $\sigma_{t0looper}$~50 ps/ sqrt($N_{crossings}$)
- Tracking improvement and ambiguity resolution
  - Inward vs outward arm
  - Reduce clone rate



For those events w/o loopers: Inclusive EventT0

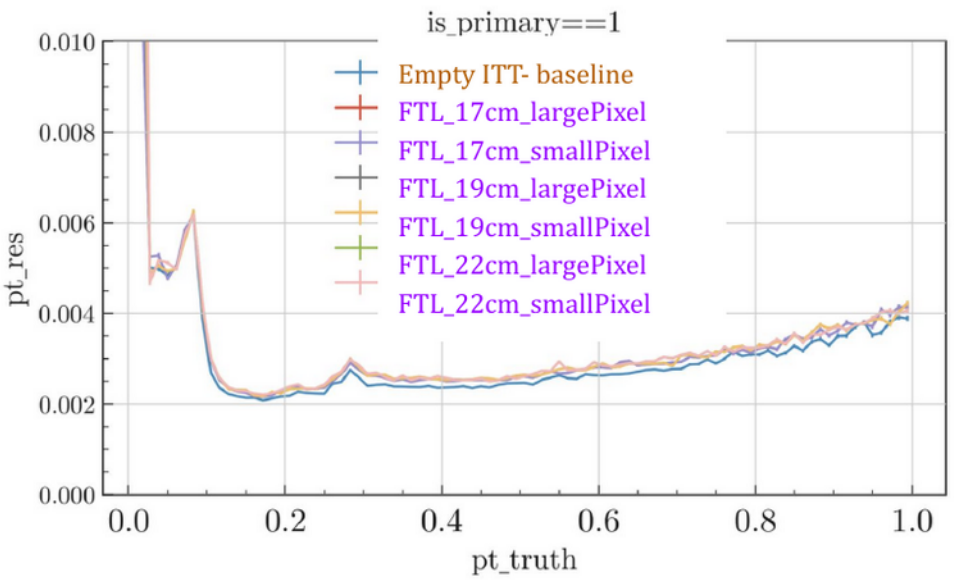
Preliminary idea:

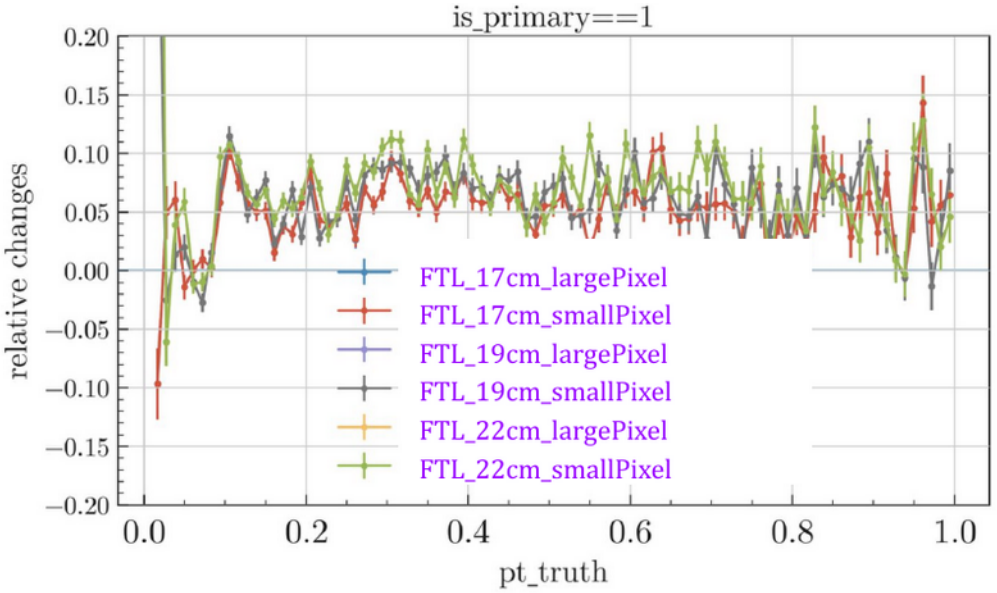
- Derive t0^ with PID and p for each tracks in one event
- Update PID and p with the new t0
- Repeat the steps iteratively

Could be something unique for Belle II !

Impact on tracking

- Evaluating the impact on tracking:





- Impact of the additional point is not positive (actually the resolution is slightly worse than with empty ITT);
- This first test was done with “MC tracks” i.e. with tracks where hits are correctly associated to each track;
- Similar conclusions were drawn from the first attempt to study the STL performance.

Impact on tracking

- In general, we do not expect tracking to improve wrt the current detectors (we are replacing O(10) CDC points with 1 or 2 points);
- We expect some degradation in the momentum resolution, especially for intermediate-momentum tracks;

- I think that the real benefit of FTL/STL on tracking will be on:
  - help connecting the VTX and oDC track segments (an empty gap might significantly reduce the overall tracking efficiency);
  - suppressing fake tracks;

- All this requires tracking expertise!

- Luckily we found a person (Martin Schmied) who can follow the work, give advice, and validate the results.

3) Acceptance

Acceptance

- The acceptance of the current detector is:

  $17^o < \theta < 150^o$ $-0.8660 < \cos\theta < 0.9563$ (91.1% of the solid angle)

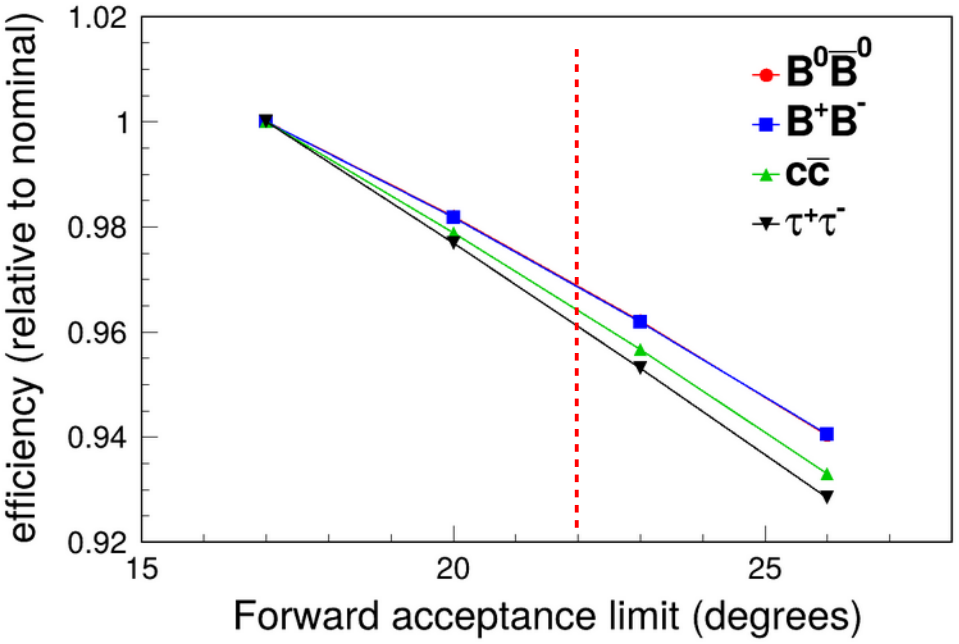
- With the new QCS it will likely become:

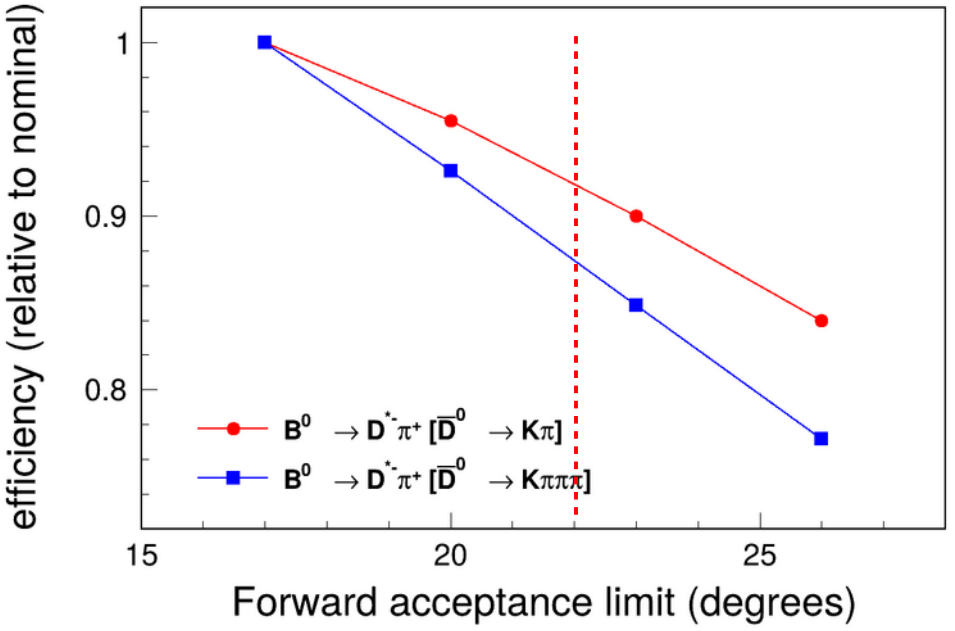
  $22^o < \theta < 150^o$ $-0.8660 < \cos\theta < 0.9271$ (89.7% of the solid angle)

- ~1.5% relative reduction on the acceptance;

- This does not automatically translate into a loss of tracking efficiency, because at Belle II tracks are boosted forward (and so we lose more if we reduce the forward acceptance).

Acceptance

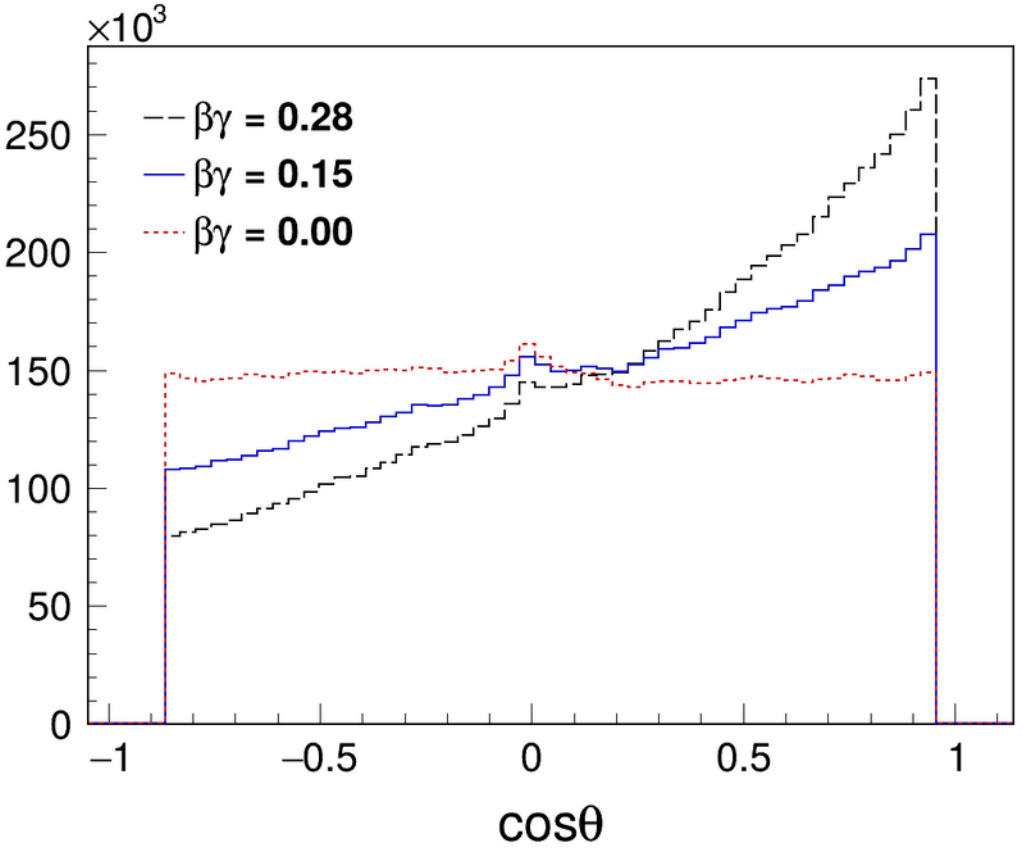




- There is some dependence on the topology;
- With the current boost, we would lose O(3%) of the tracks;
- This translates into a ~8% (~13%) loss for a 4-track (6-track) final state that is relevant for the FEI;
- If this loss of efficiency comes in exchange for a large improvement in instantaneous luminosity we would still be happy. But can we mitigate the loss?

Boost

- By reducing the energy asymmetry between HER and LER, we could reduce the loss in the forward (at the price of a somewhat larger loss in the backward);



- This would be acceptable or even welcome for the accelerator (the machine stability might improve and some backgrounds might get lower).

Boost

- By how much shall we reduce the boost?
- I ran a quick exercise, generating $B^0\overline{B}^0$ events (with one B forced to decay to $D^{*-}\,\pi^+$, $D^{*-} \rightarrow \overline{D}^0\,\pi^-$, $\overline{D}^0 \rightarrow K\pi$ or $K3\pi$) with the following configurations:

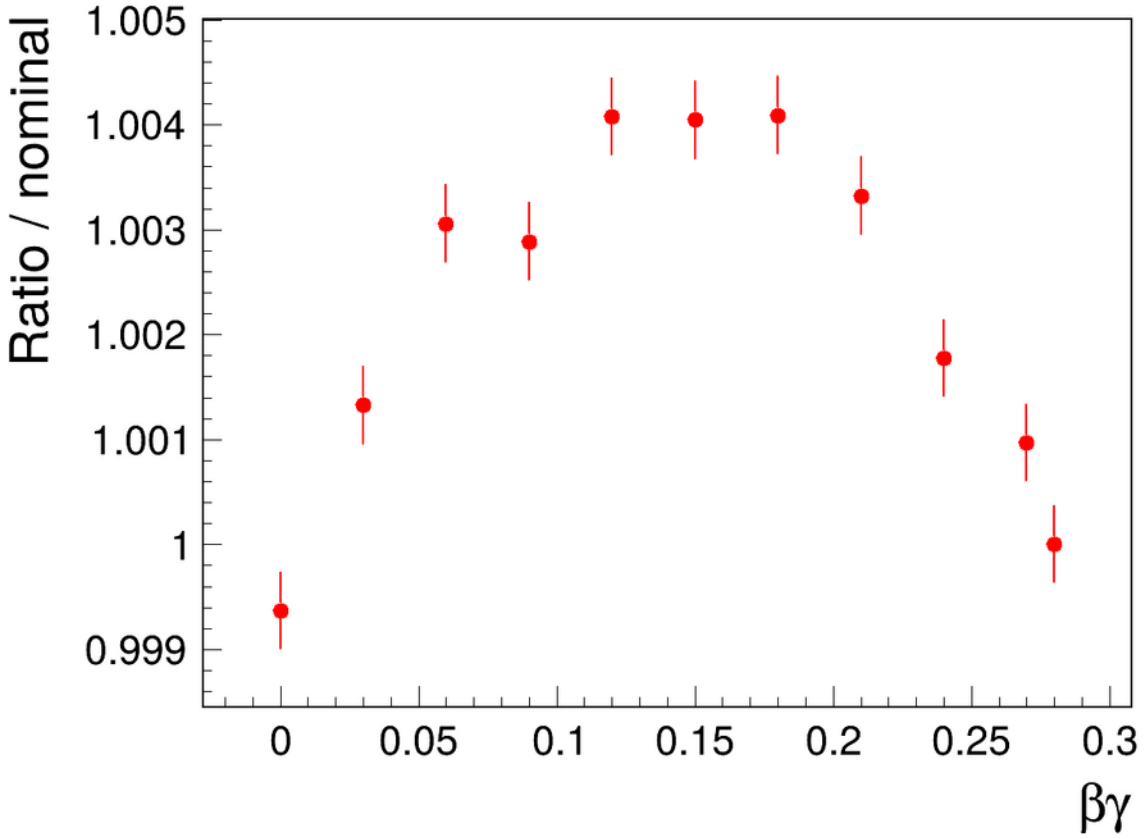
	E(HER)	E(LER)	βγ
0)	5.290	5.290	0.000
1)	5.451	5.134	0.030
2)	5.617	4.982	0.060
3)	5.788	4.835	0.090
4)	5.963	4.693	0.120
5)	6.143	4.555	0.150
6)	6.327	4.423	0.180
7)	6.516	4.295	0.210
8)	6.710	4.171	0.240
9)	6.908	4.051	0.270
Nominal	7.004	4.002	0.284

Shortcut: I set to 0 the crossing angle between HER and LER (I do not expect this to have large effects)

Still colliding beams at (0, 0, 0)

Tracking efficiency

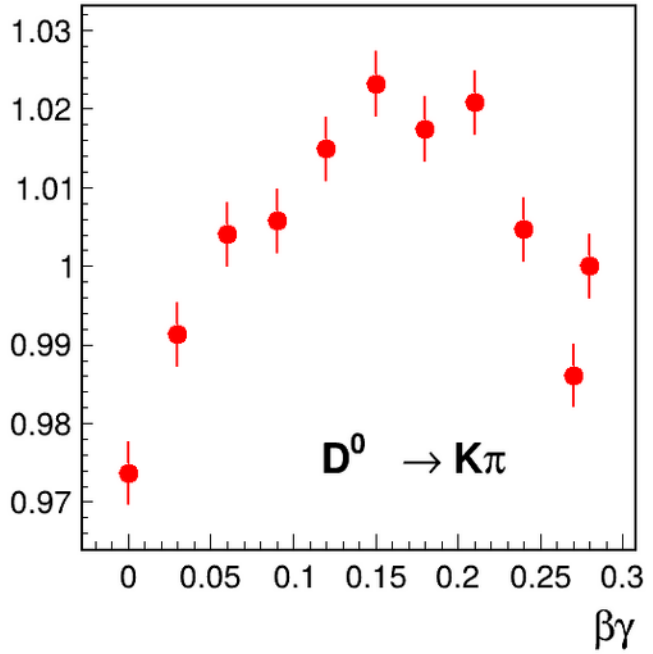
- Results:

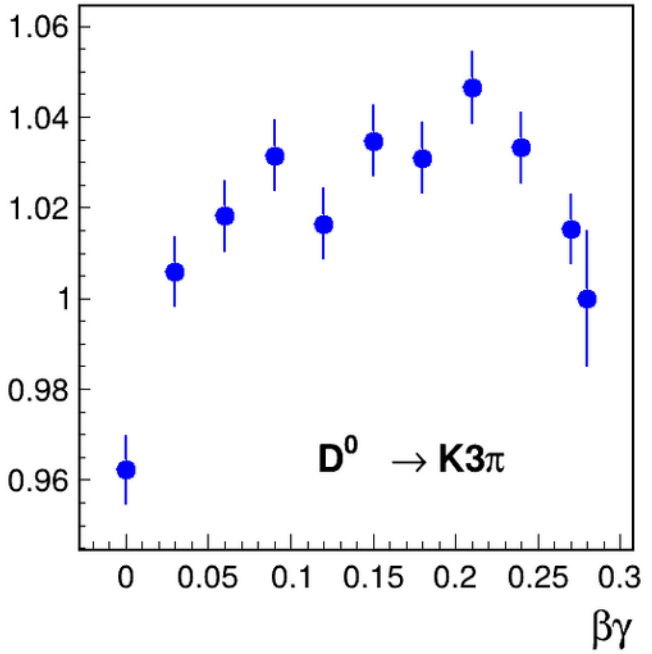


- Compared to the nominal boost, we can recover something by lowering the boost to ~0.18;
- The gain is not large anyway (~0.5%).

B reconstruction efficiency

- Similar results are obtained when comparing the yields of fully reconstructed B decays:



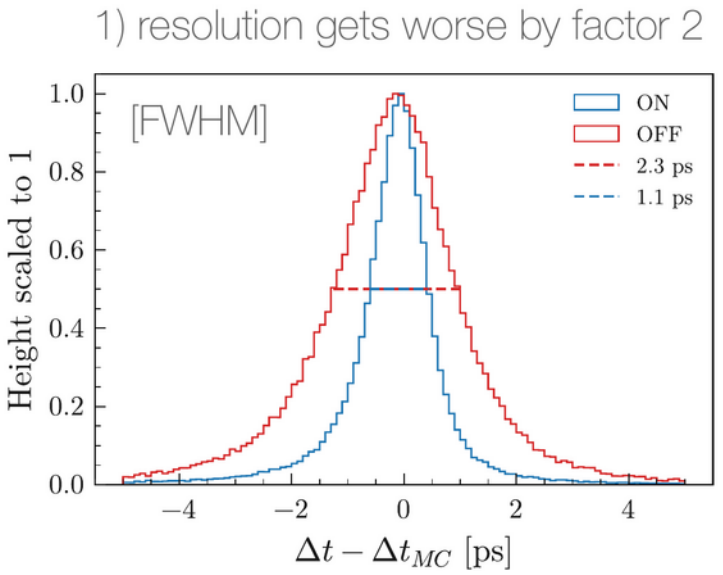


(I feel less sure about these results because I had issues with the MC truth association – or maybe some assumptions I made were not 100% correct)

Drawbacks

- Reducing the boost will have an impact especially on time-dependent B decay analyses: the distance Δz between the two B decay vertices (or between the beamspot and the tag B decay vertex in $B \rightarrow \pi^0\pi^0$) will be reduced, and the relative uncertainty on Δt will increase;

- The TDCPV group already went through the exercise of estimating the loss of sensitivity of their analyses when facing a large degradation of Δz resolution when we turned off the PXD;
- Conclusions: a factor 2 worsening of the resolution only translates into a 10-15% decrease in the sensitivity of the TD asymmetry (see e.g. here);



- I am in touch with the TDCPV conveners for more studies/feedback.

Acceptance – conclusions

- Reducing the forward acceptance, will have an impact – of O(10%) – on the reconstruction of common B decay topologies;
- This should come in exchange for a significant increase of the instantaneous luminosity, so that eventually we will gain in terms of physics;

- By reducing the boost to ~0.18 we can recover part of this loss, with an impact on TDCPV analyses that I think will be acceptable;
- Still, the gain does not look to me sufficiently large to justify a change of the boost, **unless there are additional benefits on the machine** (higher lumi and/or smaller backgrounds);

- Caveat: this is the first quick and dirty exercise I ran, some details that I overlooked might be important;
- And in general, the gain/loss depends on the topology under study.

4) Outlook

Beam backgrounds

- Beam backgrounds play a major role in what we want to study, we want to show that the upgraded detector will cope much better with harsh background conditions than the current one;

- We have a contact person (Bogdan Kutsenko) who will generate the background overlay files for post LS2 conditions for all the subdectectors;

- We have to provide him the geometries of the new subdetectors though (the ball is in our court!):
  - VTX and FTL should be there already;
  - STL?
  - at some point we will have to make some assumptions on the CDC;

- Efforts of studying the performance (of e.g. the FEI) using the older background campaign are ongoing.

Long(er) term physics studies

We are considering the following analyses:

1) $B \rightarrow K\tau\tau$

   FEI based, difficult backgrounds;

2) $B \rightarrow K\nu\nu$

   Inclusive tag approach, study impact of higher backgrounds (and limited acceptance);

3) τ LFV ($\tau \rightarrow \mu\gamma, \ldots$)

   Golden mode, unique to Belle II, can we cope with higher backgrounds?

4) TD CPV in $B \rightarrow \eta' K^0$

   Many submodes: test vertexing capabilities, flavor tagger, K_S, K_L, and π^0 reconstruction;

5, ...) $R(D^*)$, $D^0 \rightarrow \pi^0\pi^0$, $D^+ \rightarrow \pi^+\pi^0$, …

   Other important golden modes. Modes with soft leptons would be particularly interesting!

For most of the above we have already manpower assigned. The list is by no means exhaustive, anybody interested in contributing is welcome!

But we have to converge soon on the geometry and MC production!

Thank you for your attention