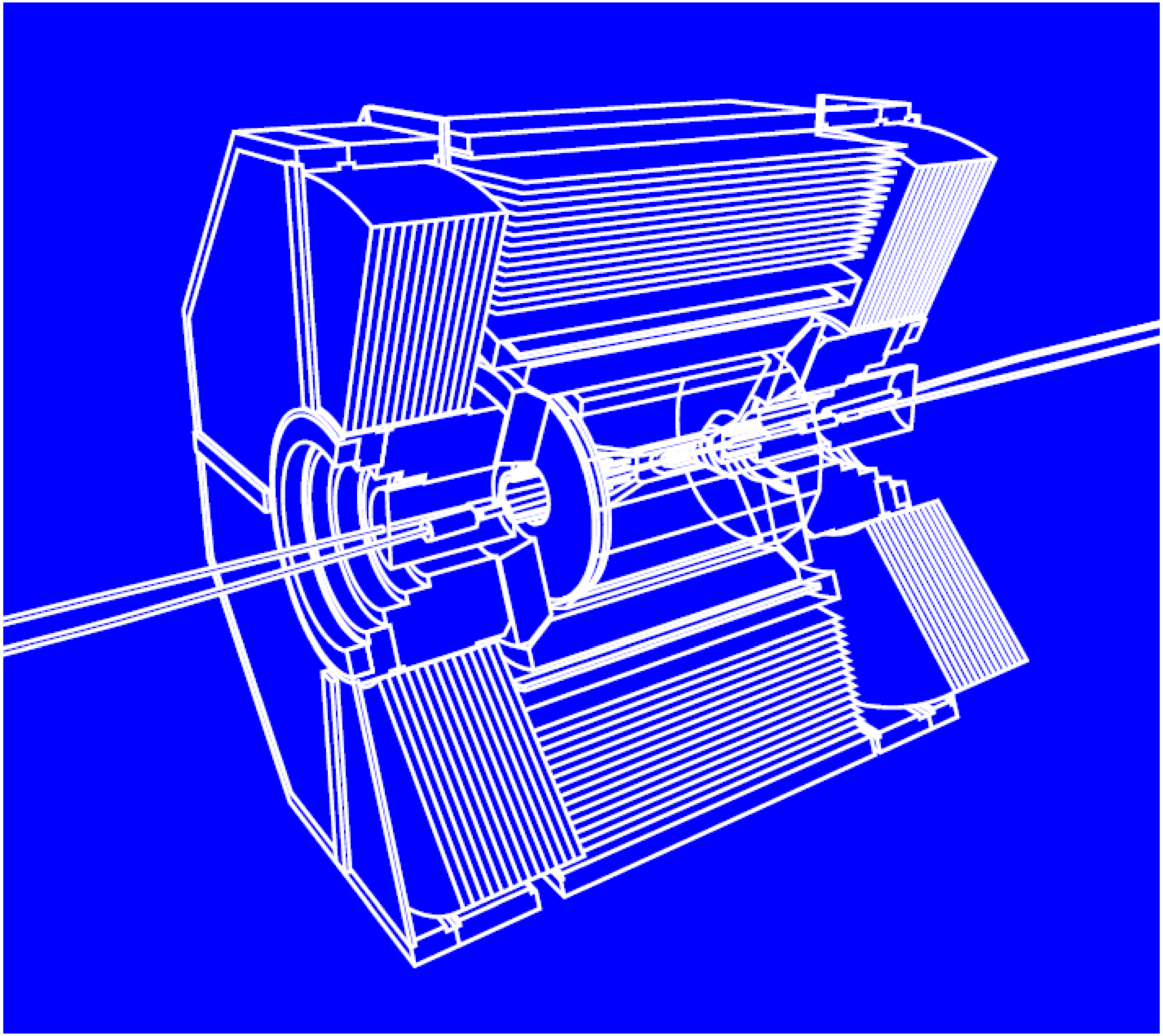
Belle II Simulation

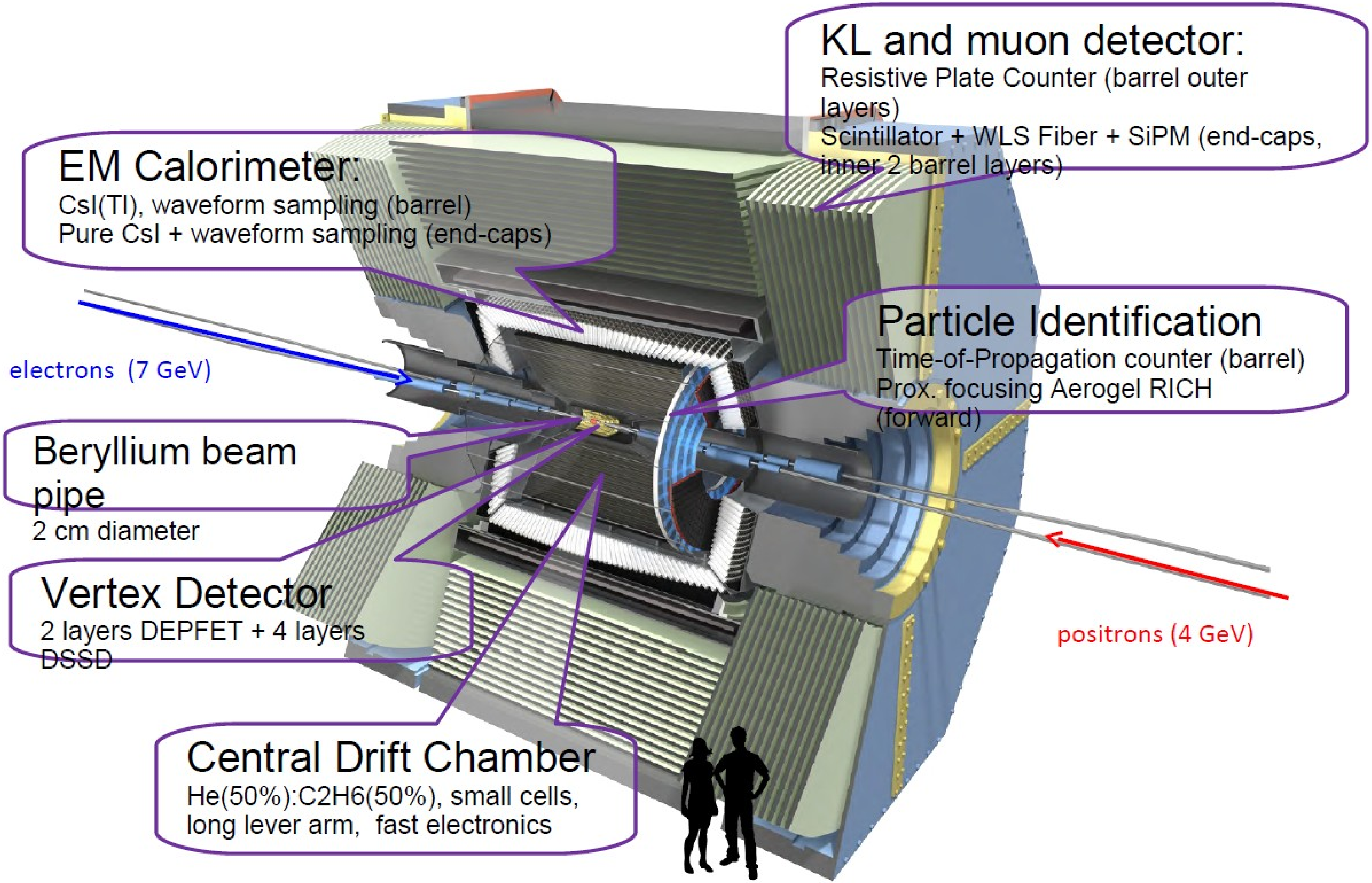


Pavel Krokovny

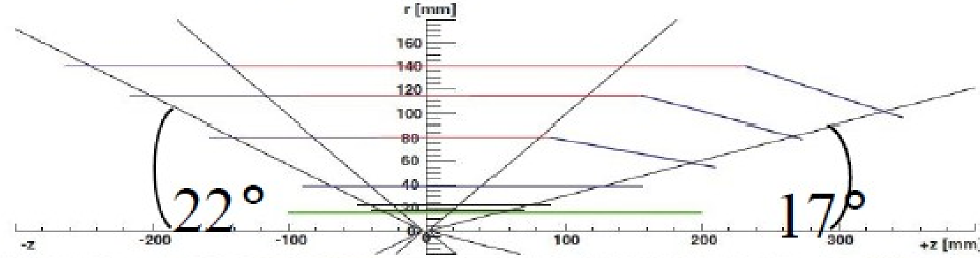
BINP

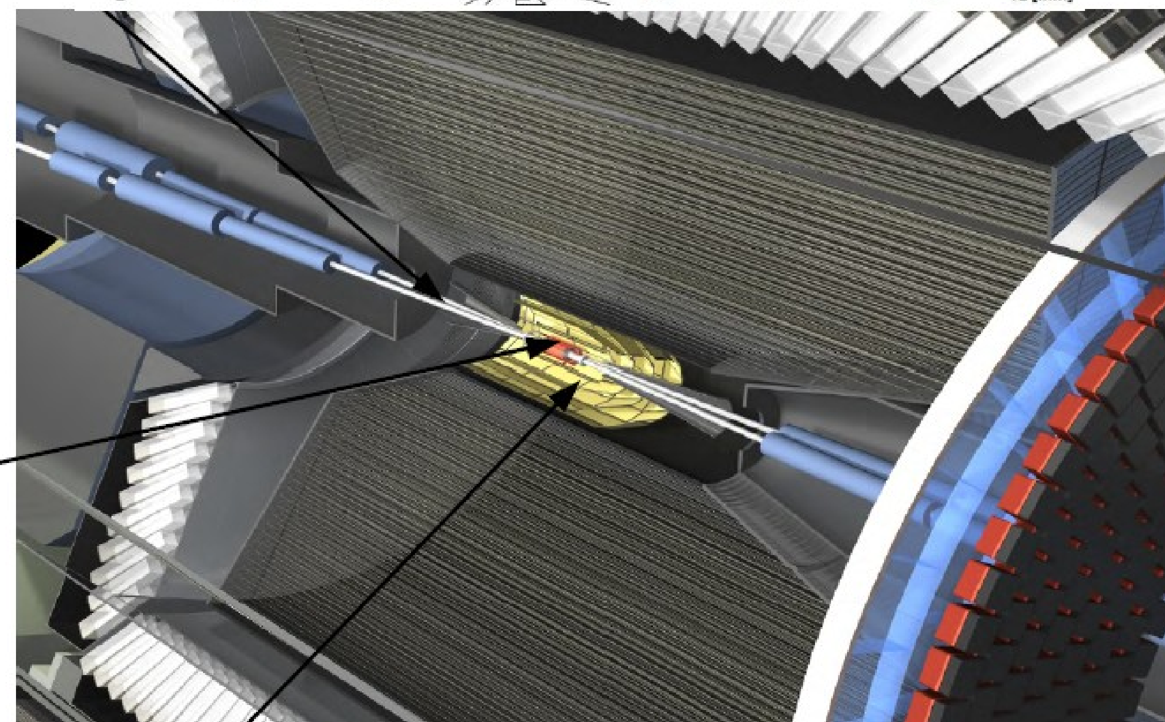
Jan 14, DESY

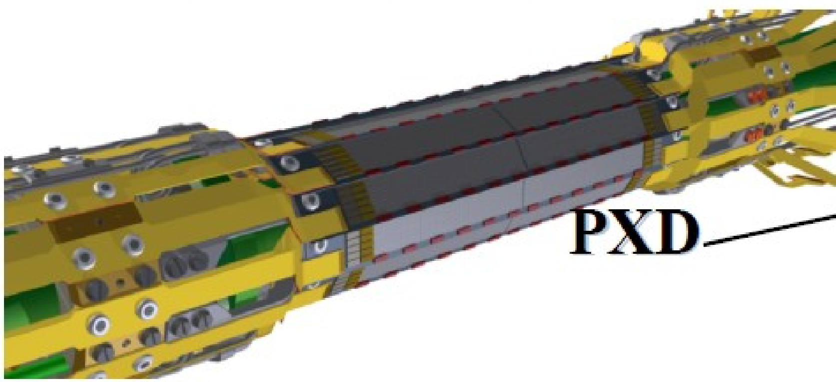
Belle-II detector

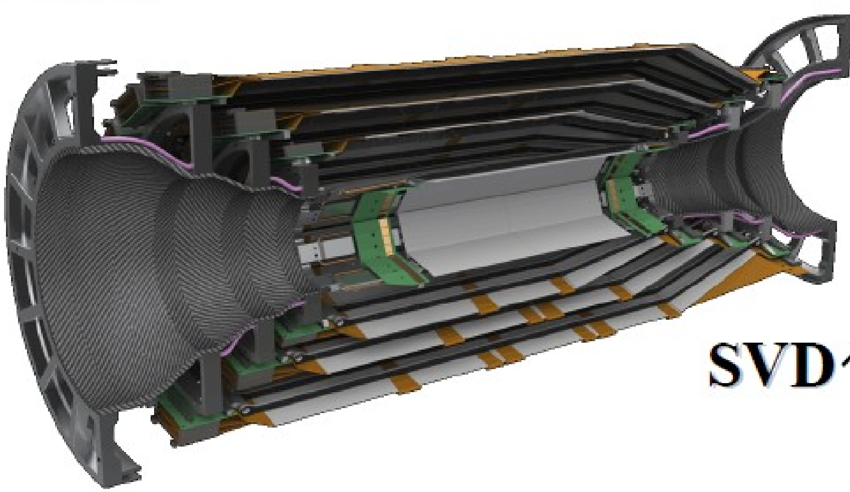


Belle II vertex region









Beam Pipe r = 10mm
PXD (2 layers DEPFET)
Layer 1 r = 14mm
Layer 2 r = 22mm
SVD (4 layers DSSD)
Layer 3 r = 38mm
Layer 4 r = 80mm
Layer 5 r = 105mm
Layer 6 r = 135mm

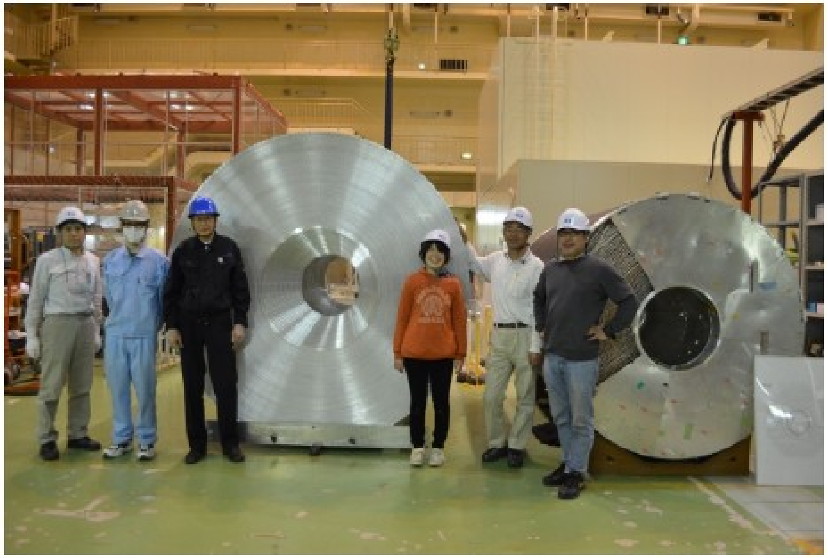
Central Drift Chamber (CDC)

- **Larger outer radius**
- **Smaller cells near the beam pipe**
- **Faster readout electronics**

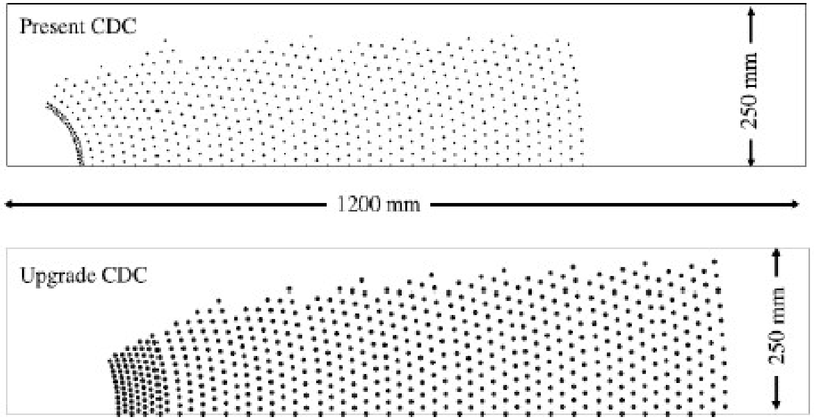
$$\sigma_{P_t}/P_t = 0.11\% P_t(\text{GeV}/c) \oplus 0.30\%/\beta$$

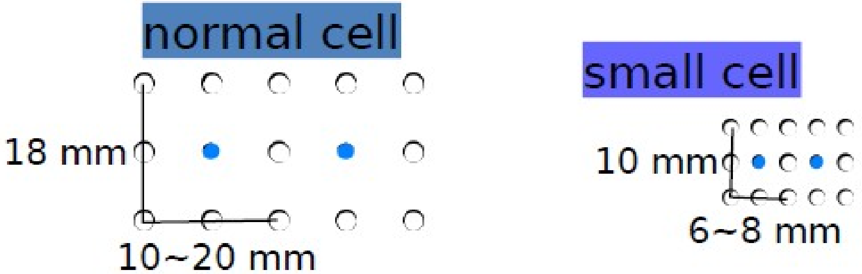
$$\sigma(dE/dx) \approx 6\%$$

	Belle	Belle II
inner most sense wire	r=88mm	r=168mm
outer most sense wire	r=863mm	r=1111.4mm
Number of layers	50	56
Total sense wires	8400	14336
Gas	$He:C_2H_6$	$He:C_2H_6$
sense wire	W(Φ30μm)	W(Φ30μm)
field wire	Al(Φ120μ)	Al(Φ120μm)
Number of wires	**41744**	**56576**



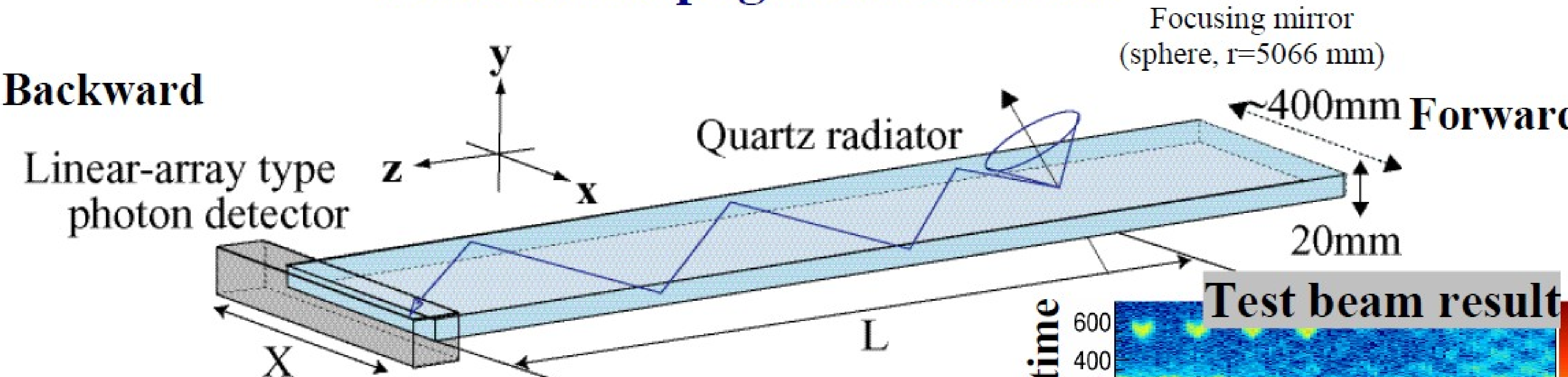
Wire Configuration

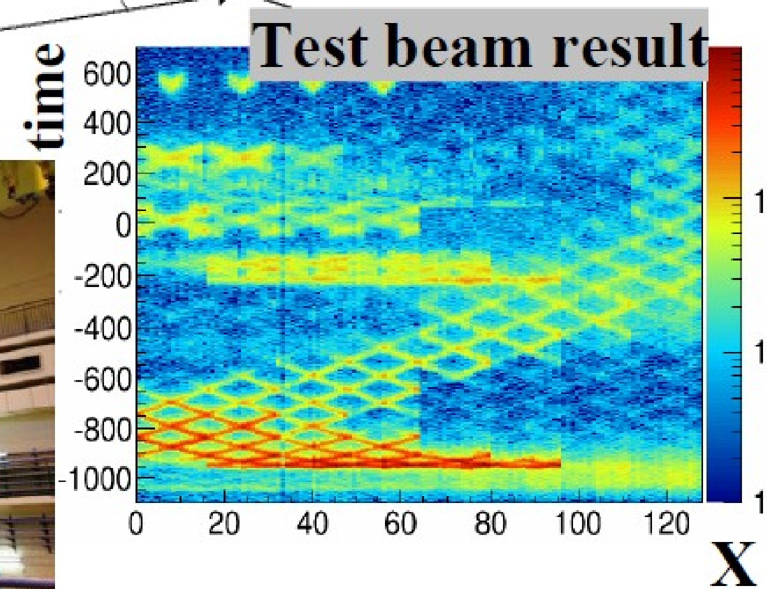




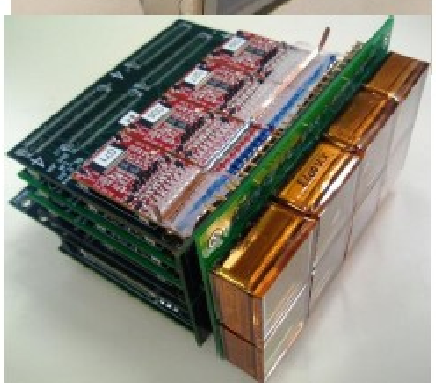
Belle II particle identification (barrel)

Time of Propagation Counter



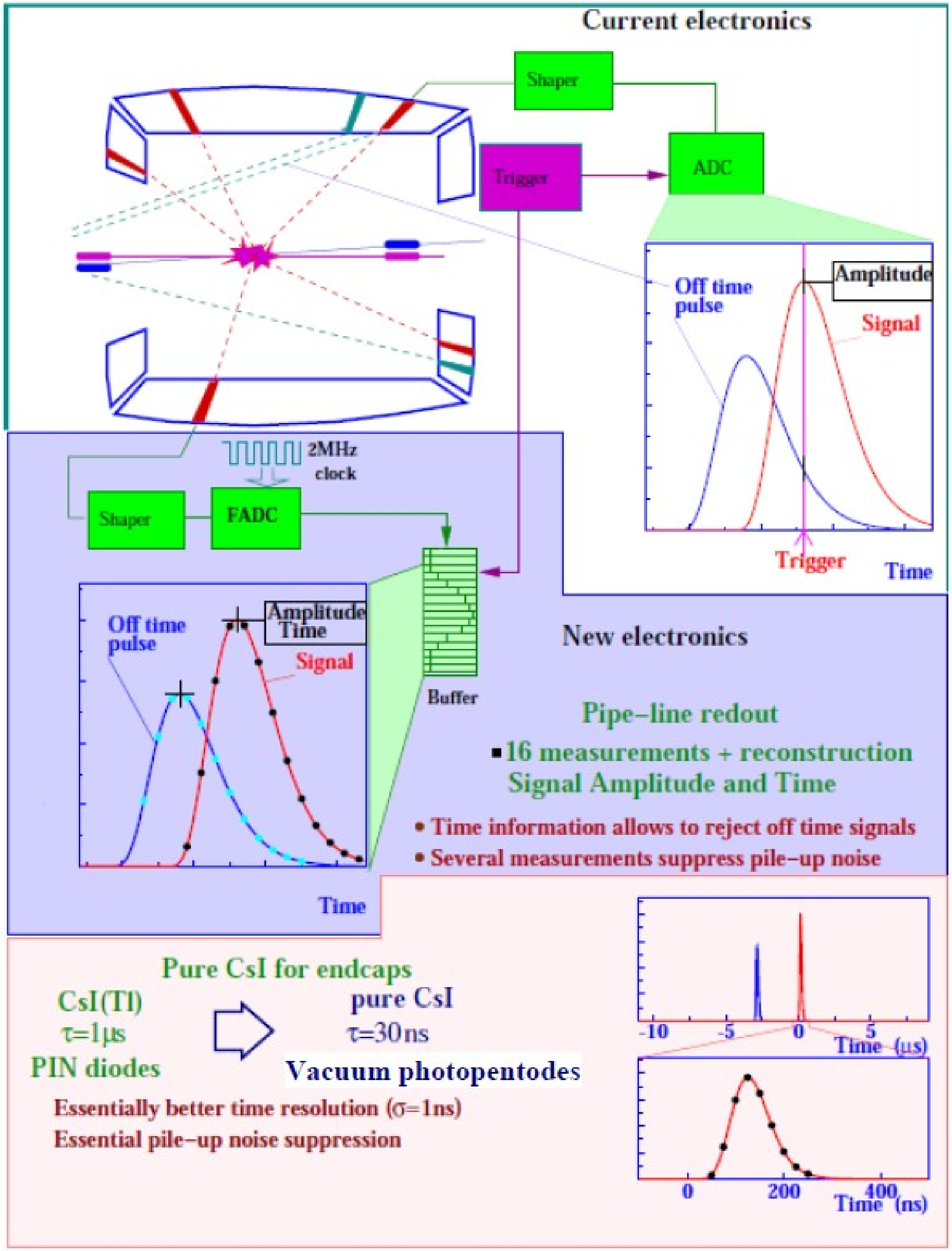


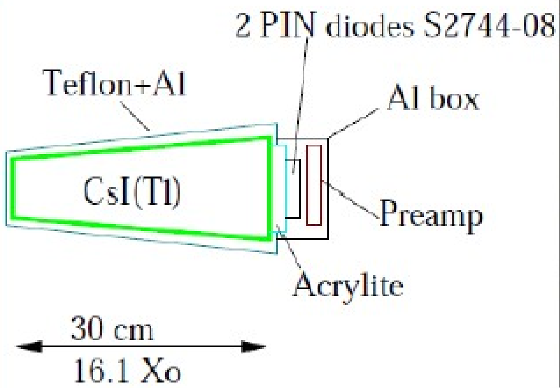
Block of 32 16-channel Hamamatsu SL10 MCP-PMT (measure x, y and time, σ_t~40 ps)



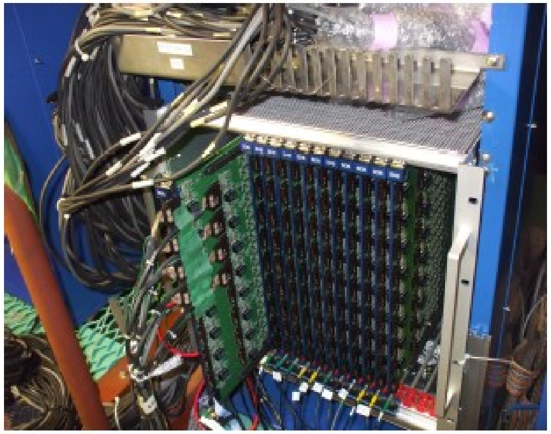
- Cherenkov ring imaging with precise time measurement.
- Measure internally reflected Cherenkov light pattern like in BABAR DIRC. Compact design, improved K/π separation.
- Reconstruct Cherenkov angle from two hit coordinates (X, Y) and time of propagation of photon.
- Focusing system to minimize chromatic effect.

Electromagnetic calorimeter (ECL), barrel





- **Barrel ECL** will be reused, new electronics with pipe-line readout and waveform analysis (16 ch Shaper-DSP board) has been developed and tested. 112 from 432 Shaper-DSP boards were produced, tested and delivered to KEK lab.
- All 6624 ECL barrel channels have been tested with new electronics (all are alive).
- Belle II DAQ electronics has been tested in the ECL data transfer runs with the frequency up to 30 kHz.
- In 2014 ECL electronics will be installed in detector.



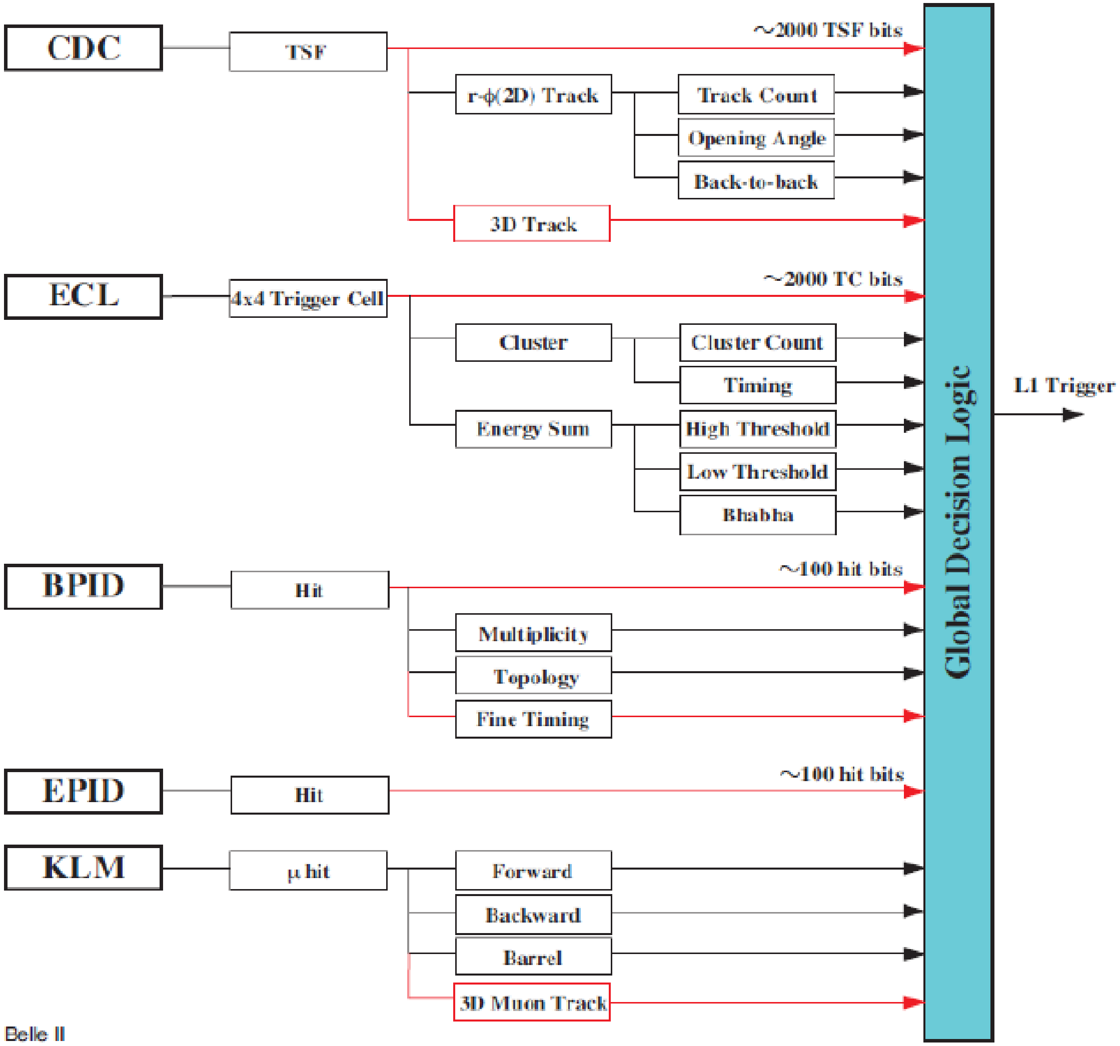
Belle II Trigger

For L = 8×10^{35} 1/cm^2/s

Physics process	Cross section (nb)	Rate (Hz)
$\Upsilon(4S) \to B\bar{B}$	1.2	960
Hadron production from continuum	2.8	2200
$\mu^+\mu^-$	0.8	640
$\tau^+\tau^-$	0.8	640
Bhabha ($\theta_{\rm lab} \geq 17°$)	44	350 [a]
$\gamma\gamma$ ($\theta_{\rm lab} \geq 17°$)	2.4	19 [a]
2γ processes ($\theta_{\rm lab} \geq 17°$, $p_t \geq 0.1$ GeV/c)	~ 80	~ 15000
Total	~ 130	~ 20000

[a] rate is pre-scaled by a factor of 1/100

- **Beam collision frequency: 508 MHz**
- **Bunch separation: ~2 ns**
- **Good physics event rate: ~20 kHz**
- **Level-1(L1) trigger max. rate: 30 kHz**
- **Nominal beam background rate: 10 MHz**
- **Trigger time uncertainty : ~2 ns**
- **L1 trigger latency: 5 μs**
- **Min. L1 time between two events: 200 ns**



Three basic triggers:

CDC based "charged" trigger, **ECL based "neutral"** trigger and **TOP based fast trigger**, which provides signal ($\sigma_t < 2$ ns) to get event start time and identify out-of-time hits in PXD+SVD to reduce data volume.

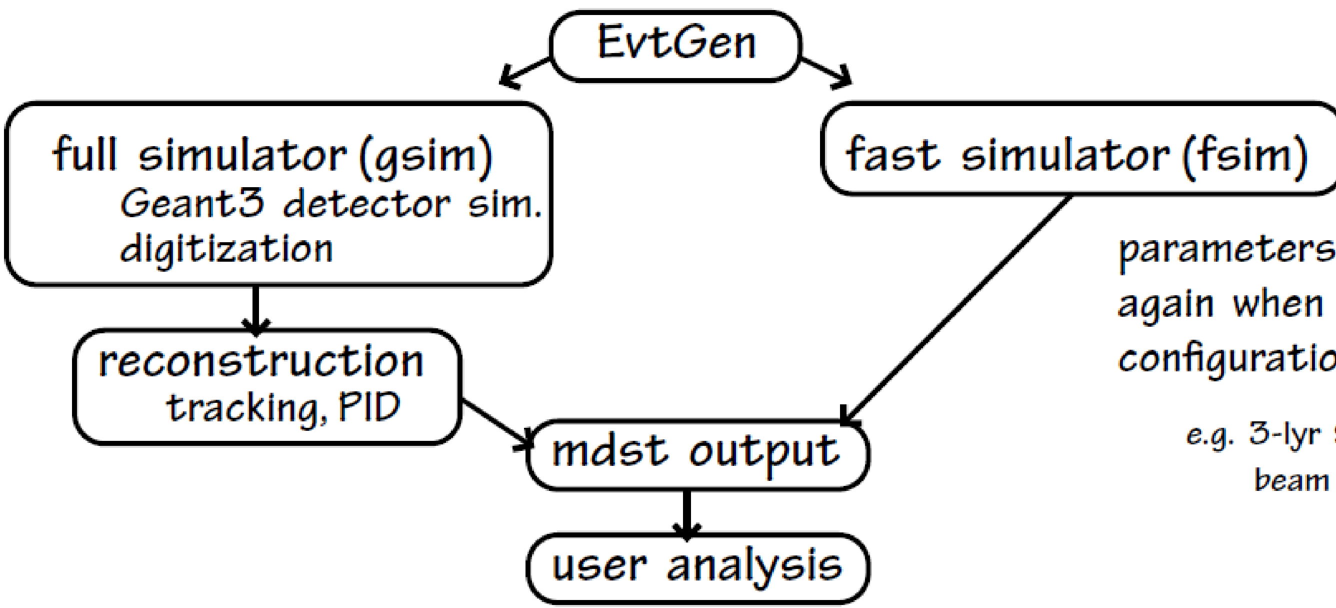
"Full" and "Fast" simulators

Belle II

Belle At the stage of the Belle detector design,
we did not have a full-detector simulator

Fortran-based fast simulator
- \+ simplified geometry (e.g. cylindrical shape SVD)
- \+ resolution : output from TRACKERR (tracking)
- \+ smeared energy / position resolution (the outer detector ?)

Full simulator w/ Geant3 under basf



parameters have to be tuned again when the detector configuration is changed

e.g. 3-lyr SVD1.0 → 4-lyr SVD2.0
beam BG effect

"Full" and "Fast" simulators

Belle II

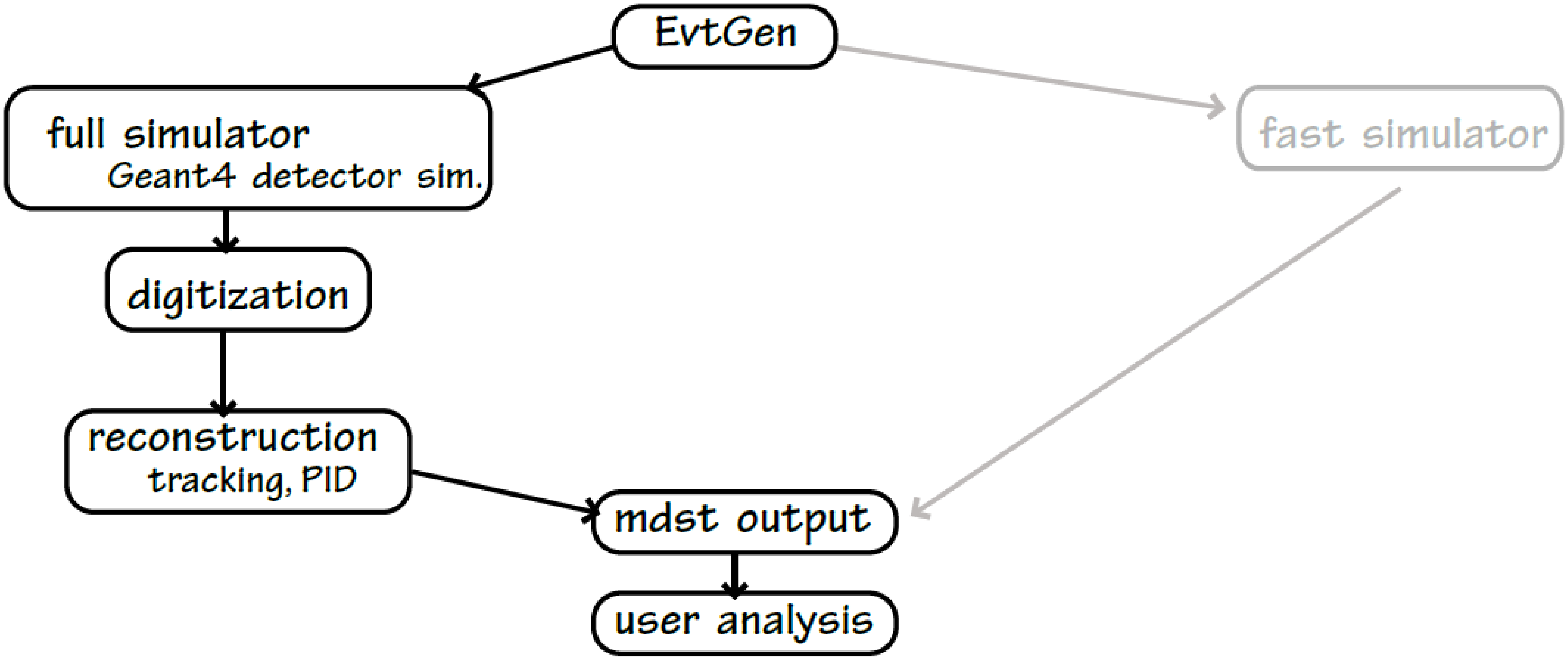
Belle full simulator was emulated for the Belle II study

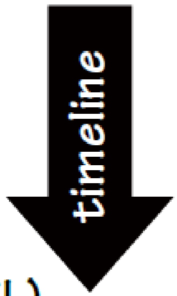
- \+ 4-layer SVD → 6-layer SVD
- \+ removal of ACC → TOP material to check $\gamma/\pi 0$ in ECL

Full simulator w/ Geant4 under basf2

- \+ time-consuming (esp. Cherenkov photon in PID, shower in ECL)

Fast simulation (Full+Fast hybrid ?)





Fast simulator

To make the simulation fast

+ simplify / approximate geometry
+ reduce unnecessary particles in physics process
+ apply parameterisation
+ use appoximation model

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TOP simulation: CPU time

M.Staric (Ljubljana)

- Used to be the main CPU consumer in `FullSim`
- Reason: propagation of photons inside bars is very slow in G4
- Solution: apply quantum efficiency first and then do propagation
- Done in two steps:
  - simulation/kernel/StackingAction: prescale the number of generated photons by $\max(QE_{TOP}, QE_{ARICH}) \rightarrow$ kills 2/3 photons
  - top/simulation/SensitiveBar: apply QE at first step $\rightarrow$ kills 4/5 photons
- `FullSim` CPU now (for generic BBbar, all components):
  - w/o optical photons: 1.83 sec/event
  - w/ optical photons: 2.95 sec/event
- TOP simulation now consumes $\sim$1/3 of CPU in `FullSim`

Fast simulator

To make the simulation fast

- + simplify / approximate geometry
- + reduce unnecessary particles in physics process
- + apply parameterisation
- + use appoximation model

- Calorimeter simulation was the first to be fully replaced by fast components
  - Frozen showers (ATLAS)
  - GFlash (CMS) / FastCaloSim (ATLAS)

For Belle II

How to treat the pulse shape ?

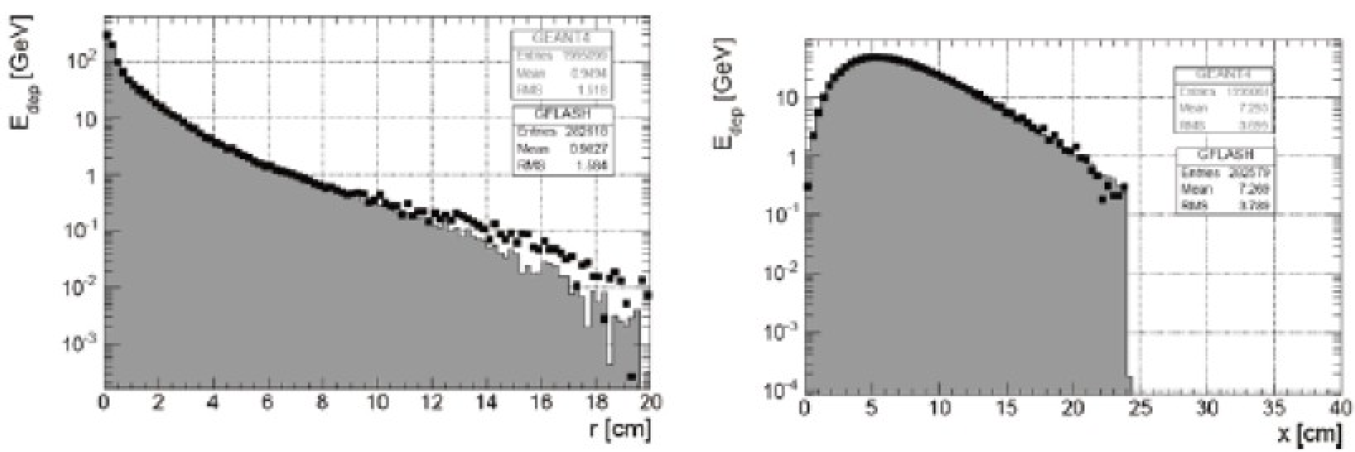
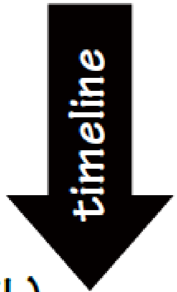


Figure 2.8: Transverse (left) and longitudinal (right) shower profiles for 50 GeV photons.

"Full" and "Fast" simulators

Belle II



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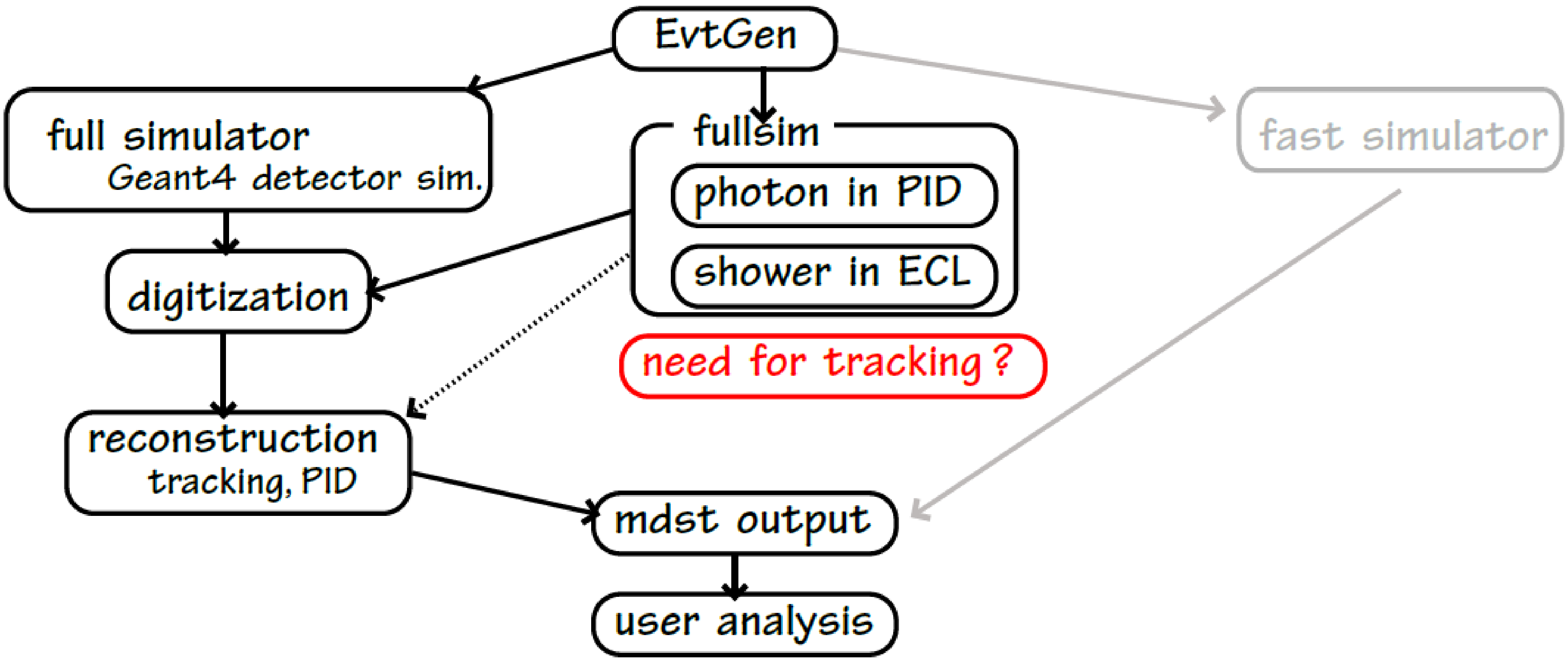
Full simulator w/ Geant4 under basf2

- + time-consuming (esp. Cherenkov photon in PID, shower in ECL)

Fast simulation (Full+Fast hybrid ?)



B → J/Ks

B → generic decay

2,000 events

w/ 20130603 head + external development version

no BG | +RBB BG

Name	Calls	Time(s)	Time(ms)/Call	Time(ms)/Call
EvtMetaGen	2001	0.015	0.007	0.007
EvtGenInput	2000	8.873	4.436	4.550
Gearbox	2000	0.002	0.001	0.001
Geometry	2000	0.001	0.001	0.001
FullSim	2000	3503.061	1751.531	~~1790.236~~ BG mixer (RBB)
PXDDigitizer	2000	10.844	5.422	58.431
PXDClusterizer	2000	3.358	1.679	5.785
SVDDigitizer	2000	274.859	137.430	→ 949.094
SVDClusterizer	2000	121.350	60.675	65.799
CDCDigitizer	2000	345.882	172.941	→ 441.758
TOPDigitizer	2000	1.053	0.526	14.428
ARICHDigitizer	2000	0.245	0.122	18.360
ECLDigitizer	2000	38.348	19.174	→ 10435.905
BKLMDigitizer	2000	3.455	1.727	1.937
EKLMDigitizer	2000	191.485	95.743	91.614
MCTrackFinder	2000	29.525	14.762	14.711
CDCMCMatching	2000	176.519	88.259	83.804
GenFitter	2000	989.710	494.855	493.774
DedxPID	2000	87.284	43.642	43.178
Ext	2000	253.499	126.749	122.068
TOPReconstructor	2000	3202.480	1601.240	1440.900
ARICHReconstructor	2000	11.555	5.777	54.622
ECLReconstructor	2000	5.503	2.751	40.173
ECLGammaReconstruct	2000	4.524	2.262	3.139
ECLPi0Reconstructor	2000	14.418	7.209	28.289
ECLMCMatching	2000	2.472	1.236	8.899
EKLMReconstructor	2000	0.290	0.145	0.166
EKLMMuonReconstruct	2000	0.002	0.001	0.001
EKLMKOLReconstructor	2000	0.123	0.062	0.068
RootOutput	2000	57.600	28.800	30.281
Total	2001	9338.697	4667.015	17141.231

Conclusion

- Study of the detector design was done with BelleII-emulated Geant3 simulator. We checked the material effect, beam background effect, etc.
- In parallel, we use a Geant4 simulation under basf2. It has more precise Belle II detector geometry: realistic PXD and TOP counters. Nowdays it became stable and started to be used for more realistic physics feasibility check.
- However, we already noticed our full simulator is slow. We have to improve the simulation itself: the optimization of the physics list, energy cut off, parameterization of the photon propagation, simplification of the geometry, etc. This work is in progres.