Diamond sensors for halo and luminosity measurements

Philip Bambade

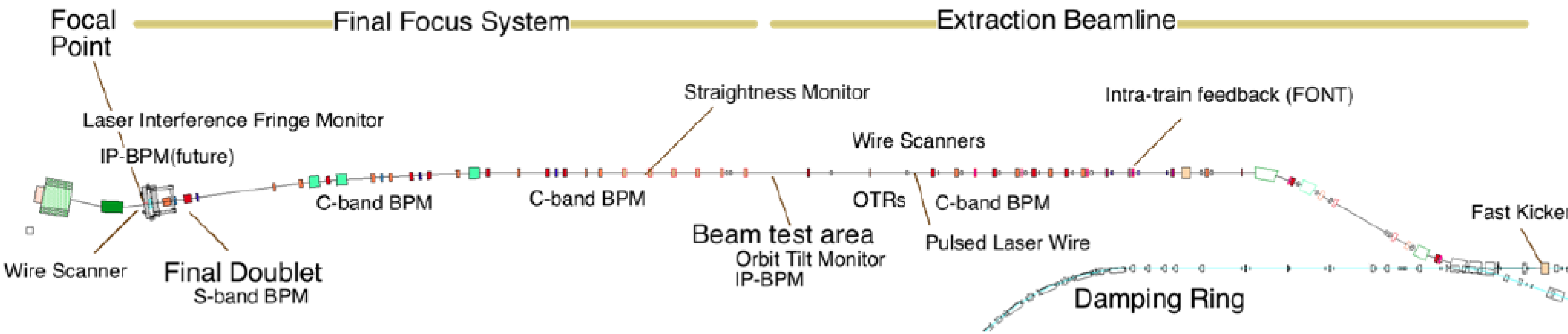
Laboratoire de l'Accélérateur Linéaire
Université Paris 11, Orsay, France

1) ATF2 LC final focus R&D
2) B meson factories : SuperB / (SuperKEKB)

starting up $\rightarrow$ collaborate

ATF2

ATF2 ➔ focus "low emittance" electron beam → 35nm



ATF2 ➔ scaled ILC (+ basis for CLIC) final focus

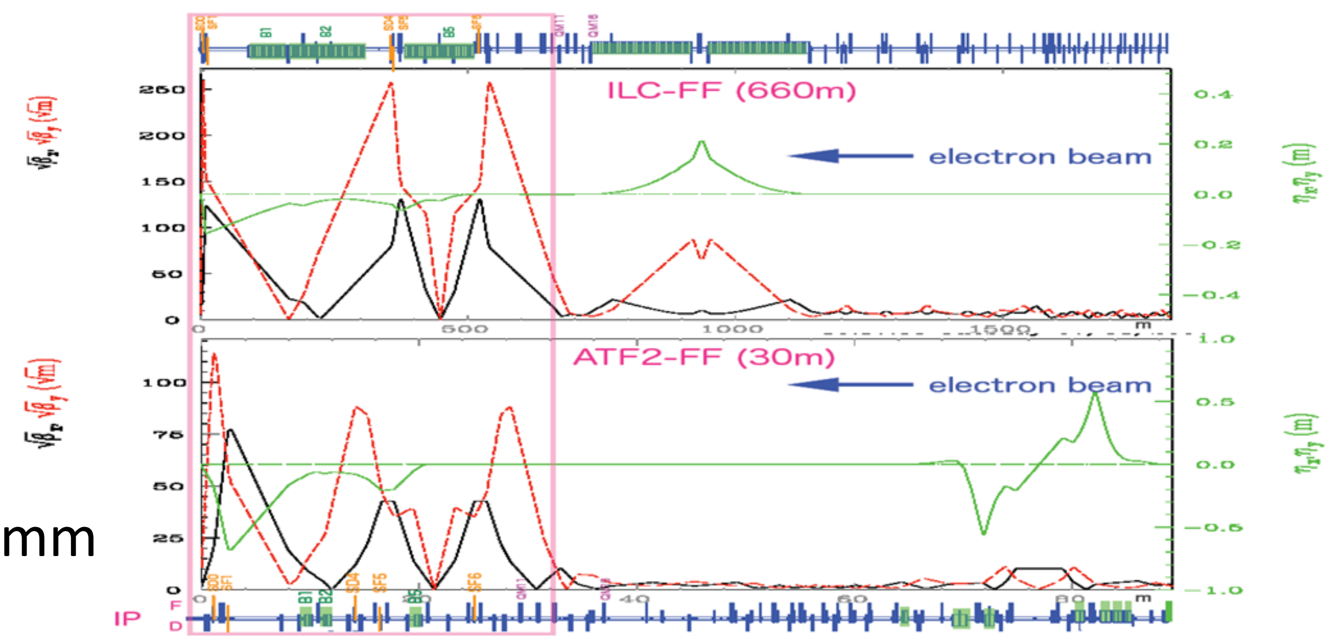
E = 1.3 GeV

N = 10^{10} e^{-} / bunch

f ~ 1.5 – 6 Hz

$\delta E/E = 8\ 10^{-4}$

$\sigma_{x,y,z}$ = 3μm, 35nm, 8mm




IP


Shintake Monitor
Monitor
IP


Final Doublet

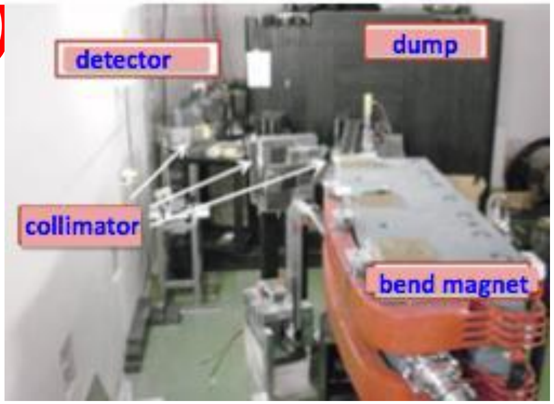
Nano-meter Beam Size Monitor

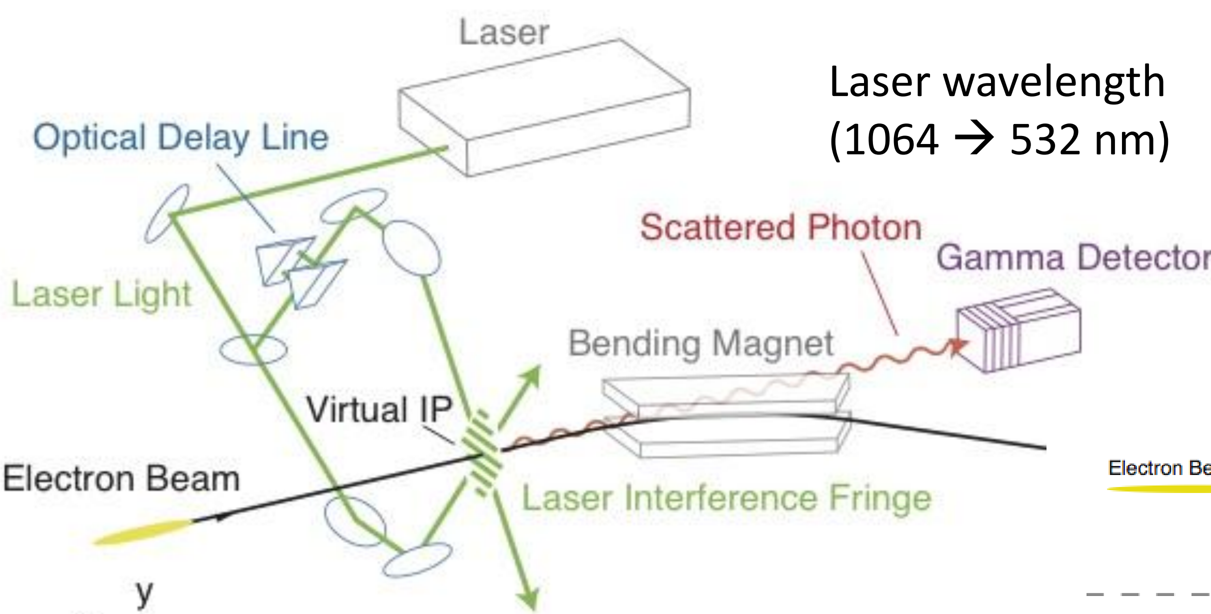
Univ. Tokyo / KEK

Beam Size Measurements at ATF2-IP

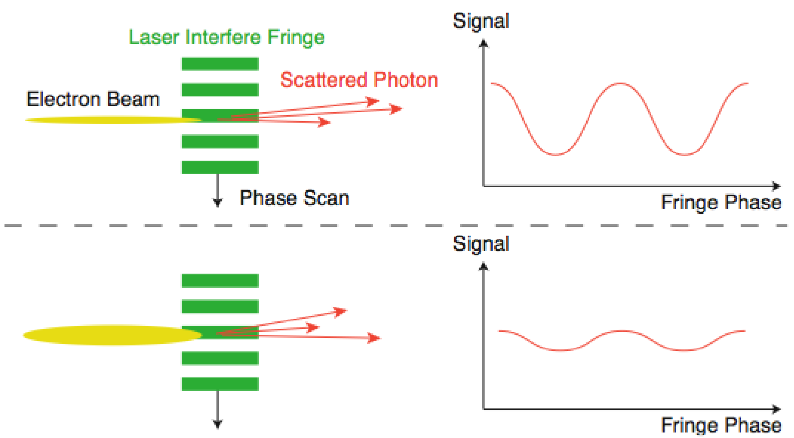
- Solid (W,C) wire Scanners (meas. for 2um or more)
- Laser interference fringe monitor (meas. for 20nm~6um)

FFTB ~70nm(measured) -> ATF2 37nm(goal)

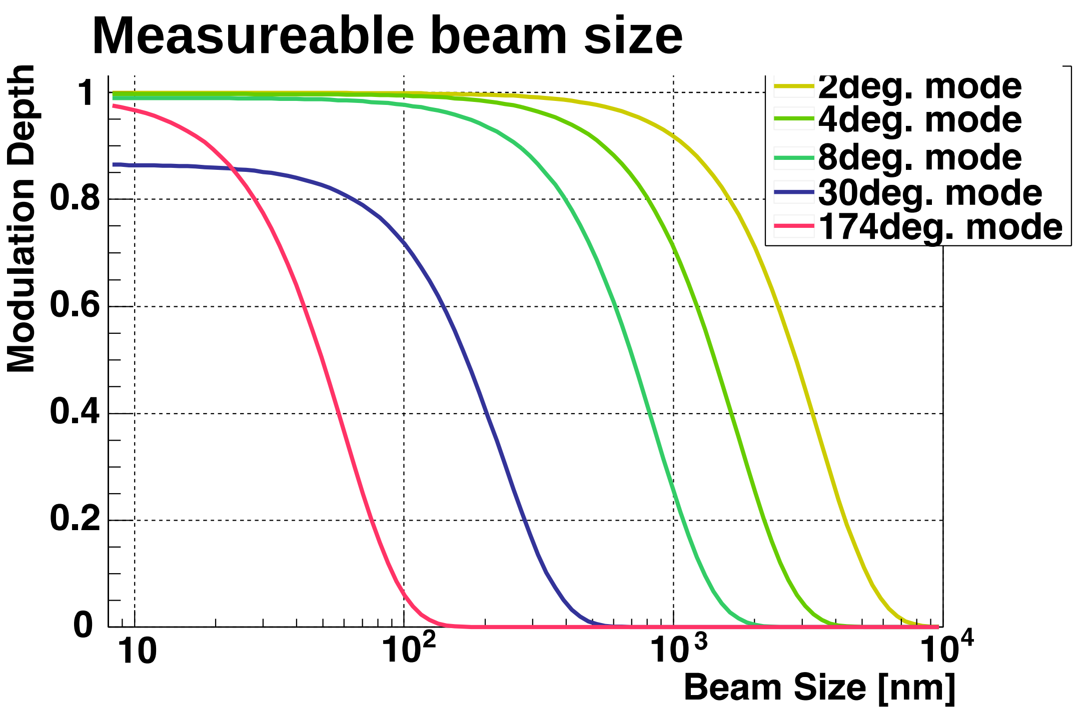


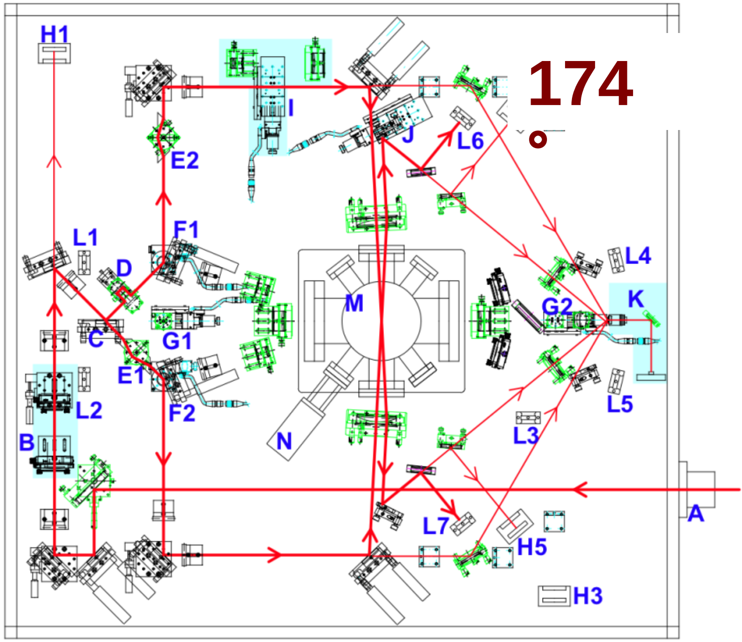


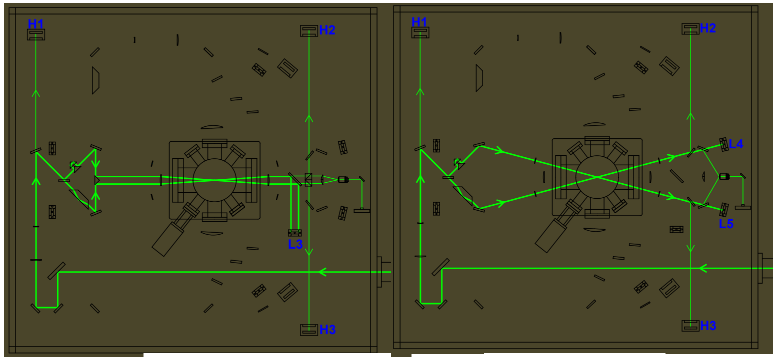
Laser wavelength
(1064 → 532 nm)



Laser Interference Fringe Monitor for ATF2



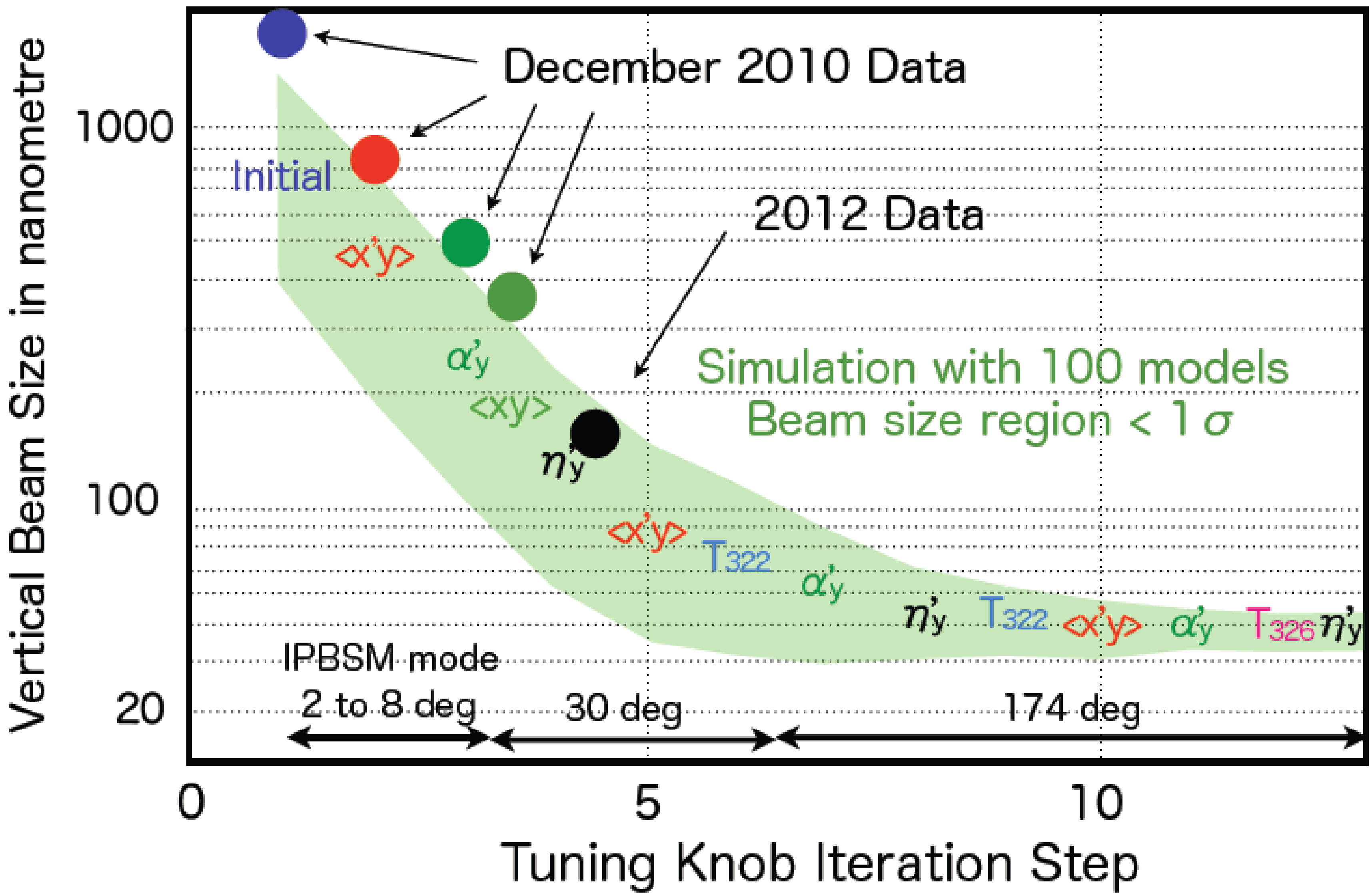




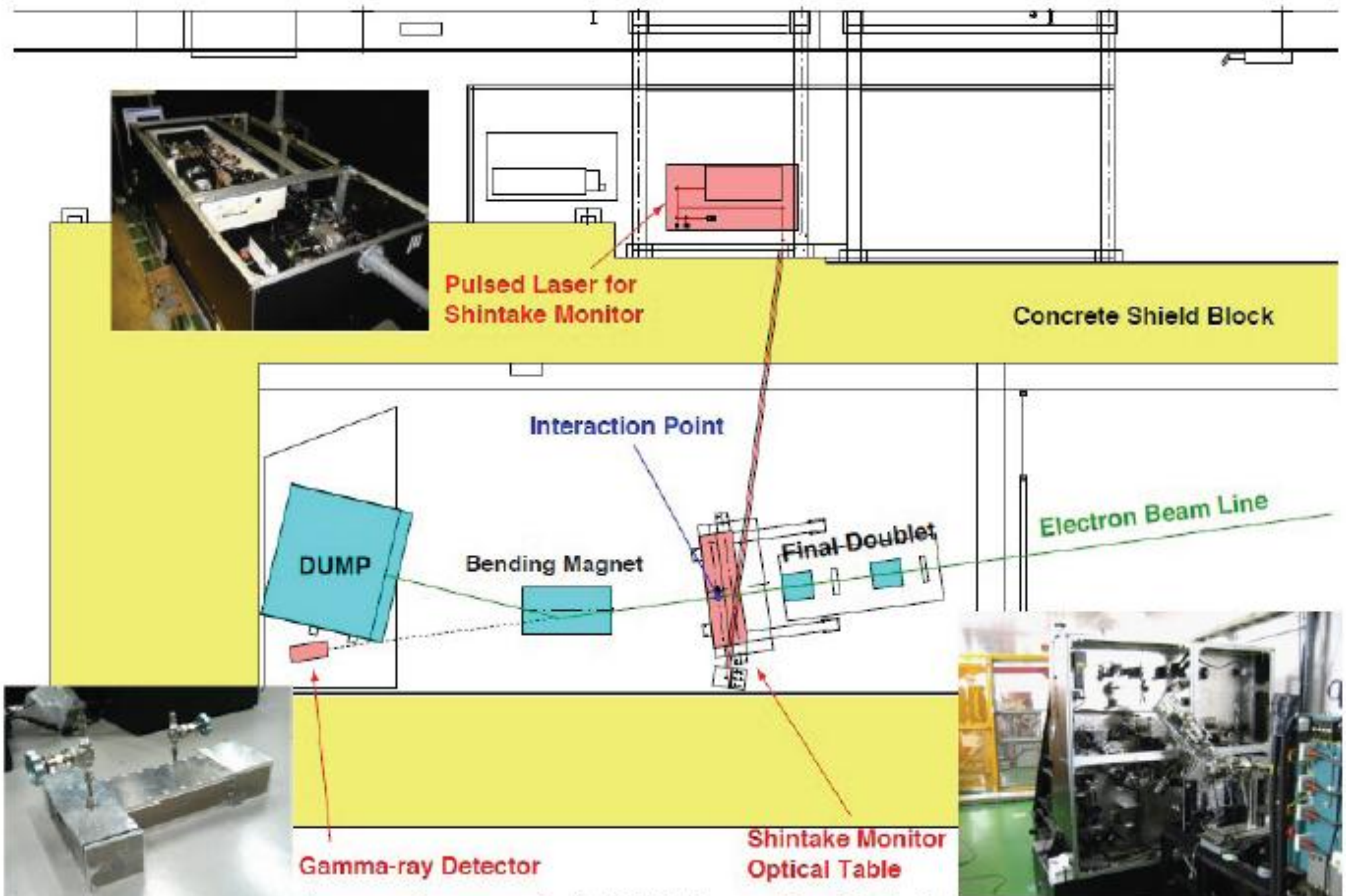
	174°	30°	8° ⟷	2°
Fringe pitch	266 nm	1.03µm	3.81µm	15.2µm
Minimum	**25 nm**	100 nm	360 nm	-
Maximum	**100 nm**	360 nm	-	6 µm

2~8° **30°**

Tuning the ATF2 vertical beam size

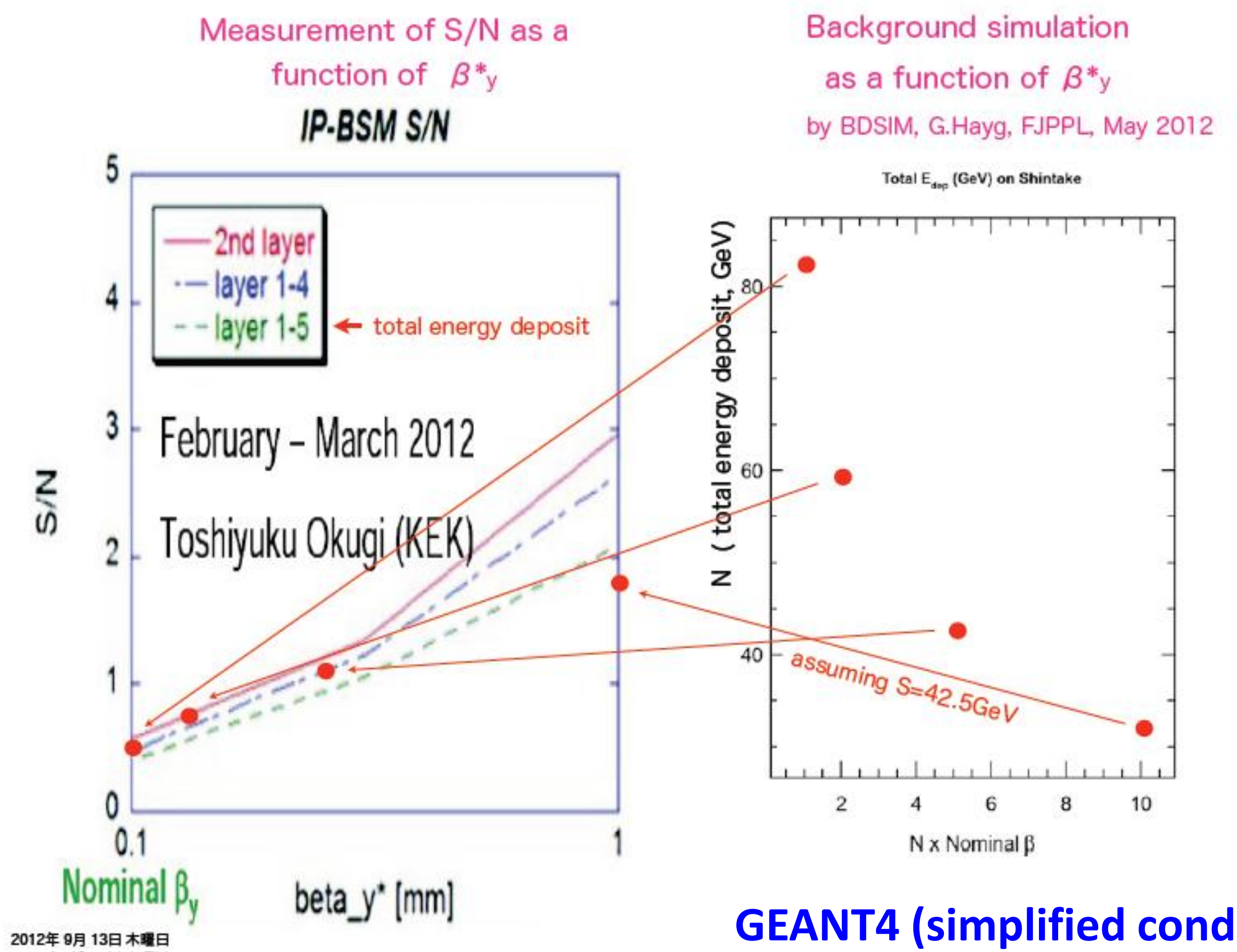


Shintake Monitor : Layout



Layout around ATF2 Interaction Point

Beam halo and BSM background issues



GEANT4 (simplified conditions)

Halo intercepted on

- **post-IP bend magnet vertical gap**
- **final doublet beam pipe**
- **chromatic correction c-band BPM apertures**

under study…

Beam halo distributions in old ATF extraction

$N_{halo} / N_{beam} \sim 10^{-3}$

arXiv:0810.5467

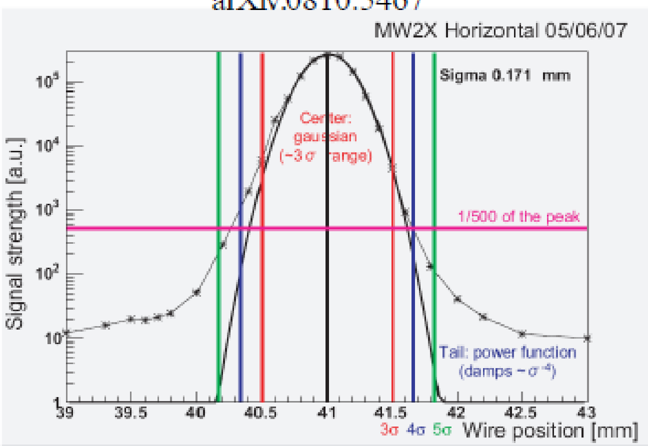


Fig. 25. Measured result of charge distribution using an ATF extraction line wire scanner.

$$\rho_{h1} = 2.2 \times 10^9 \times x^{-3.5} \quad \text{(horizontal and vertical until 6 } \sigma)$$

$$\rho_{h2} = 3.7 \times 10^8 \times x^{-2.5} \quad \text{(vertical outside 6 } \sigma)$$

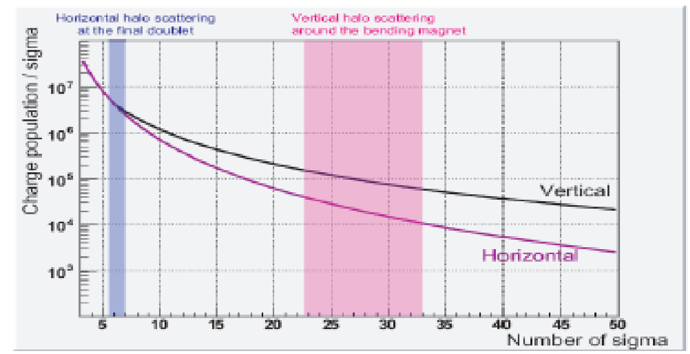


Fig. 27. Maximum charge density of the beam halo estimated by the halo measurement. Blue and purple area shows the concerned region, discussed in Section 6.2.4.

Mechanisms for halo formation and propagation

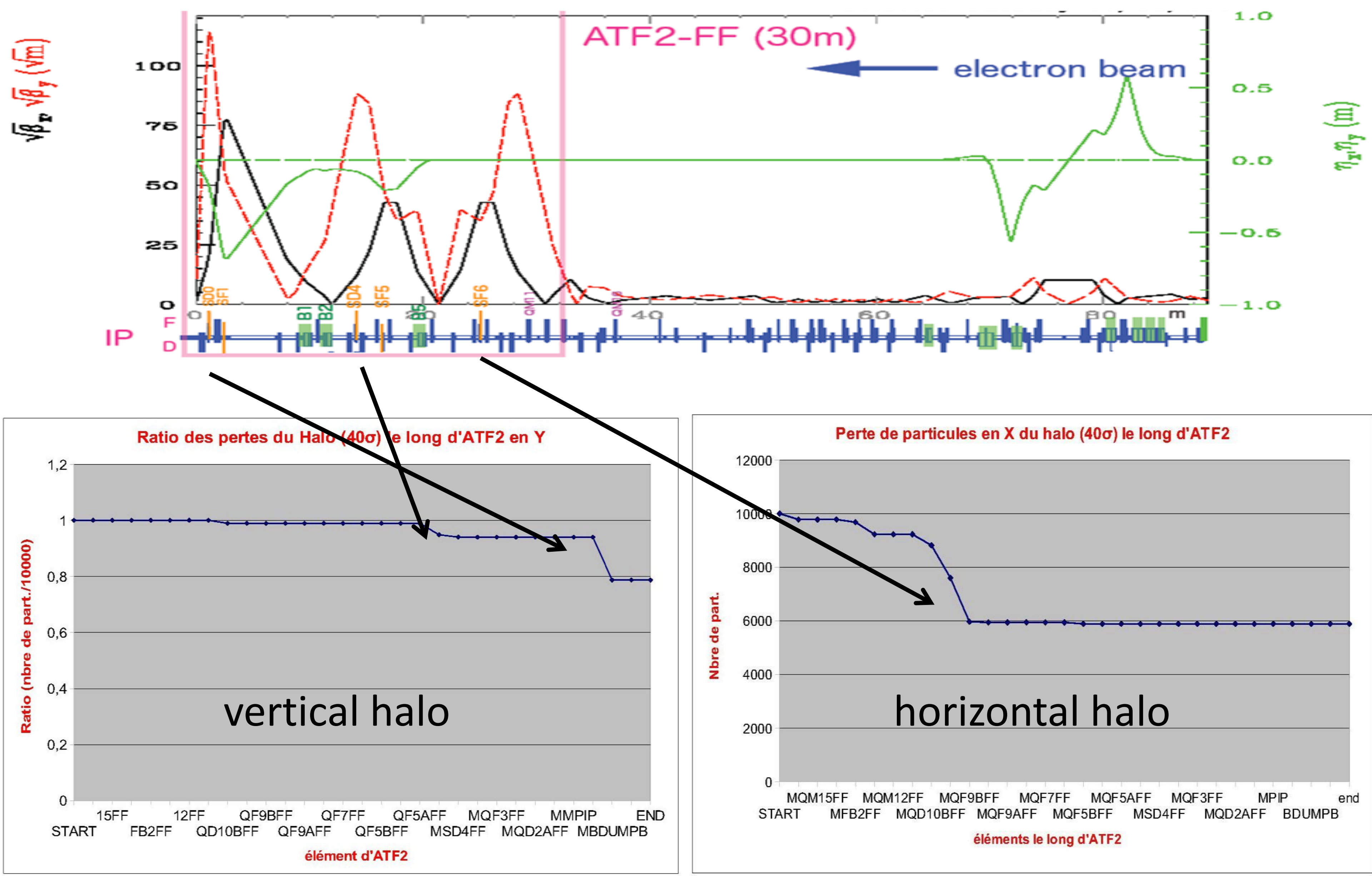
Linac → "dark currents", wake fields

Ring → multiple intra-beam Coulomb scattering, scattering beam gas and black body photons

Beam delivery & final focus → non-linearity, wake fields, re-generation from collimation, very low-Pt physics

➔ measure near IP

Beam halo distributions interception in ATF2



Location for beam halo measurement in ATF2

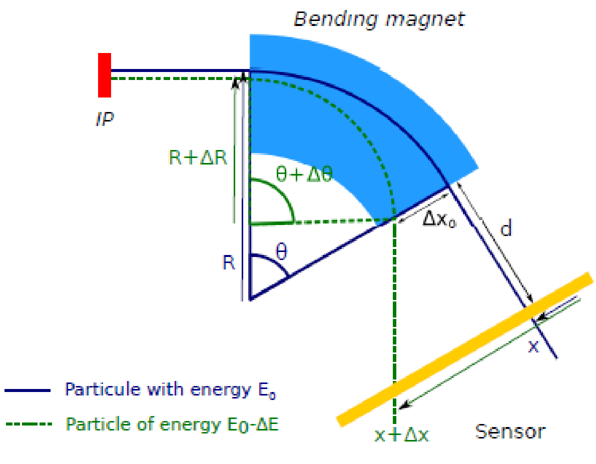
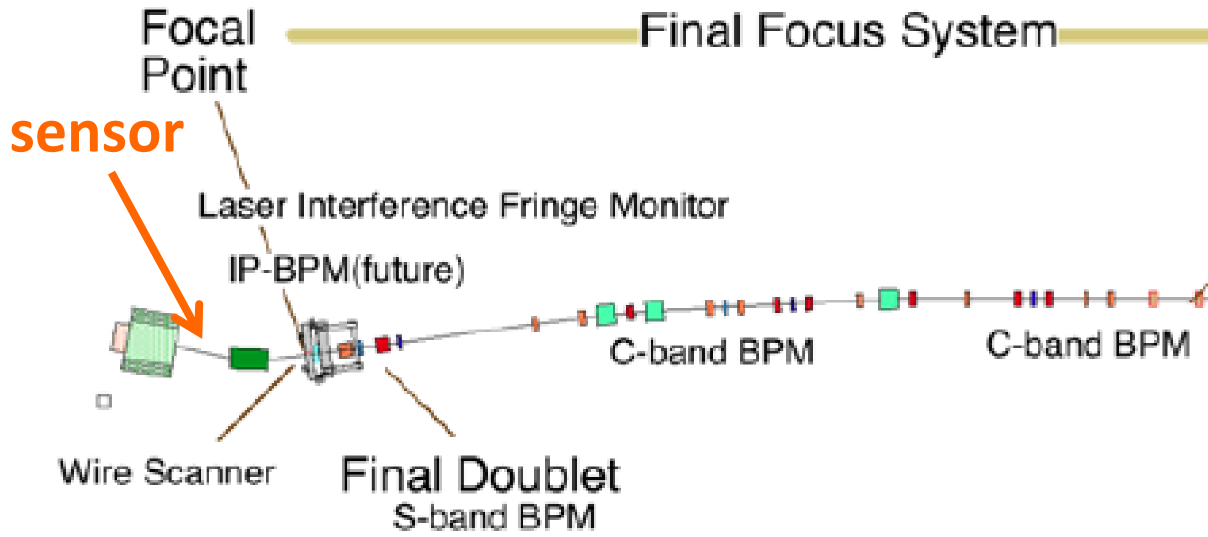
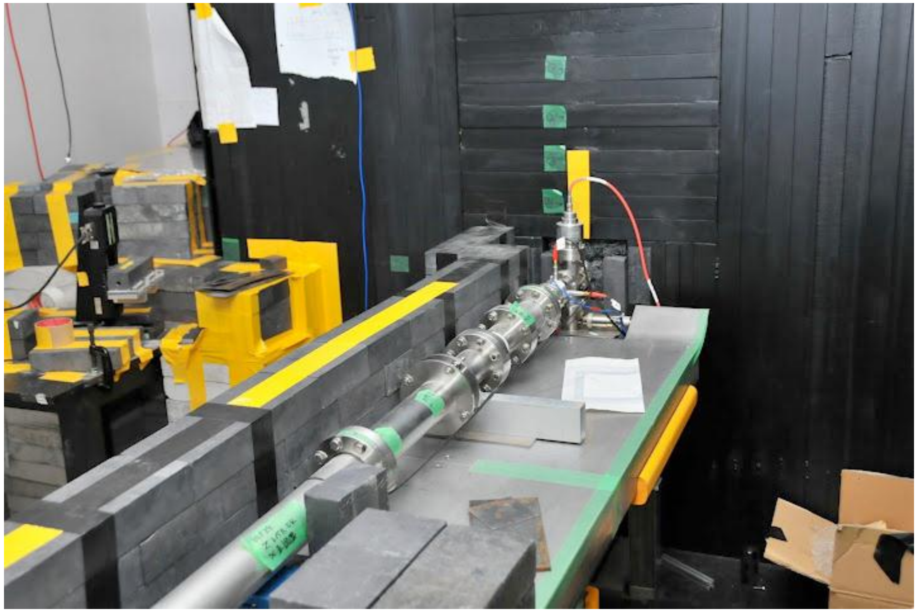
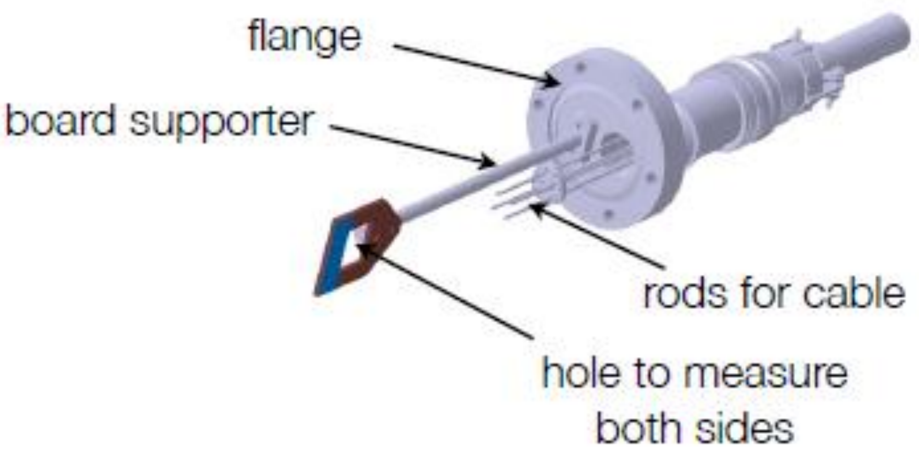


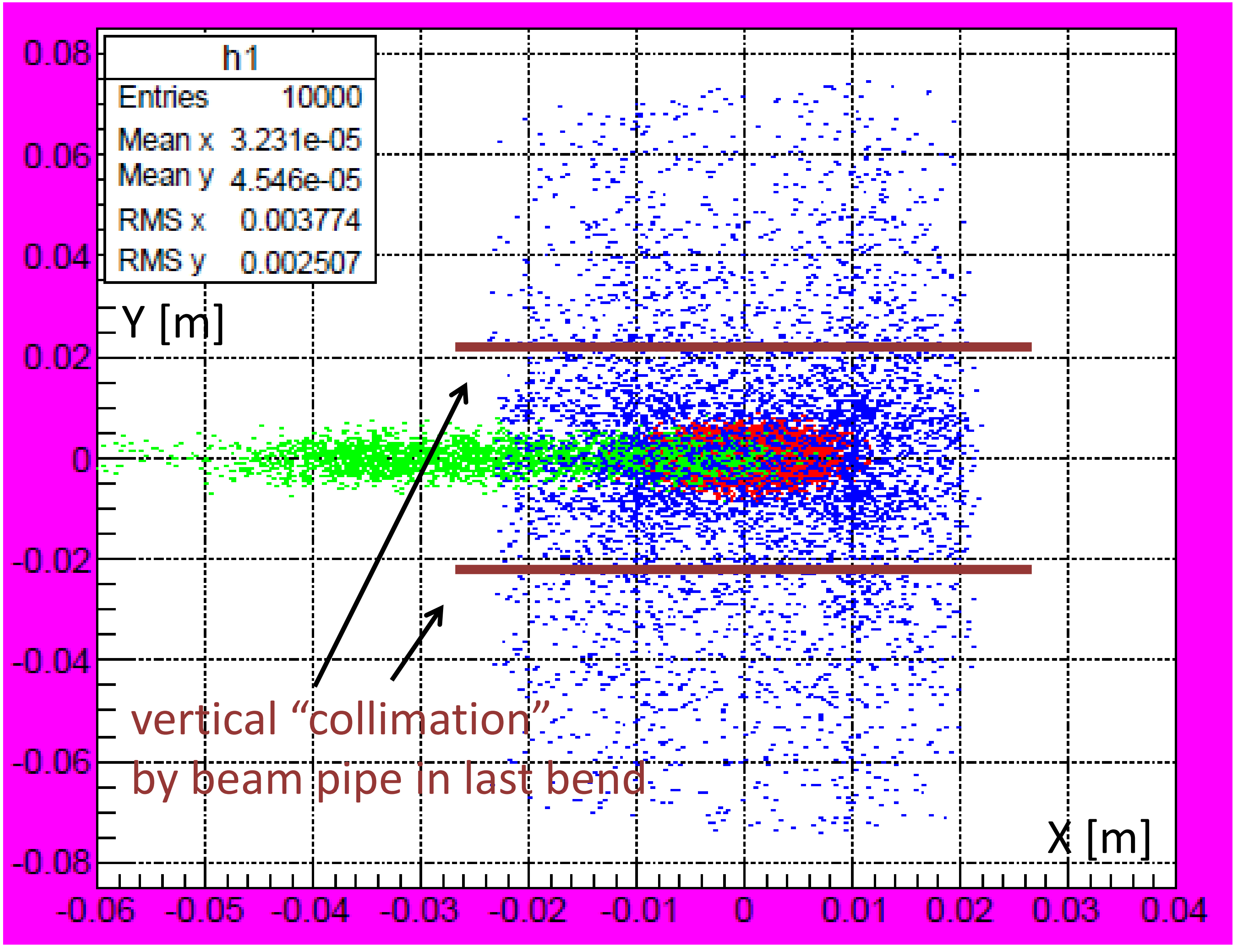
Figure: Positionning of the sensor





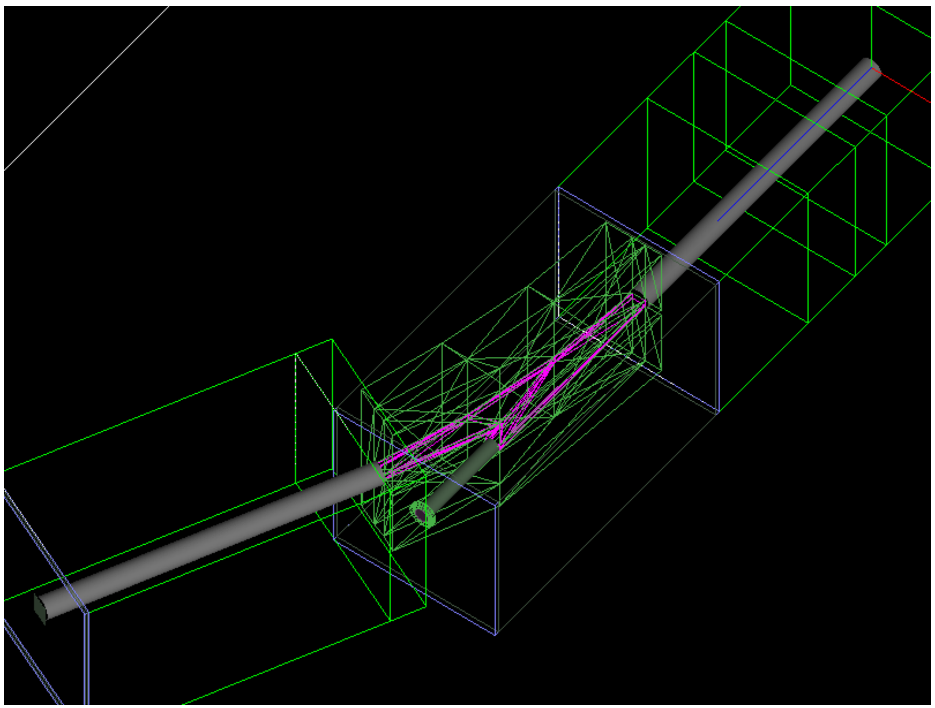


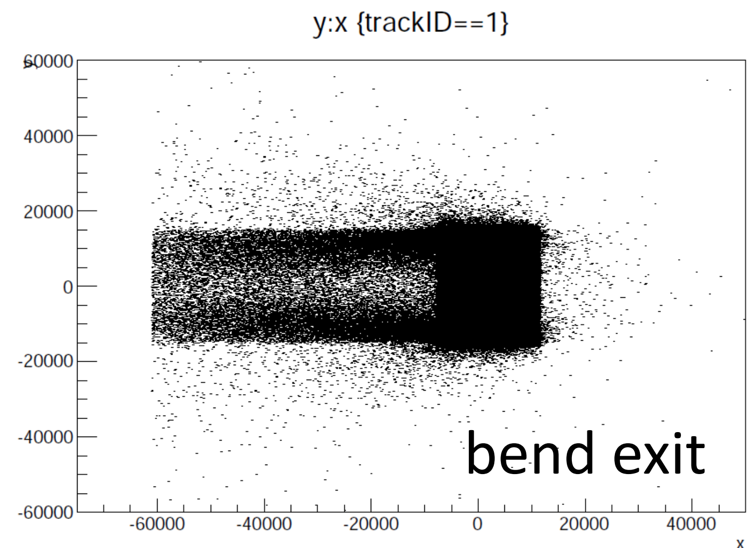
Beam halo Compton

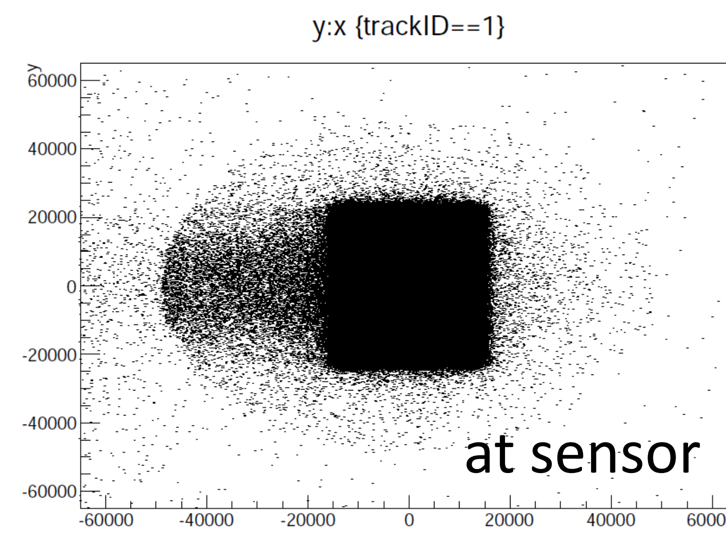


Halo re-generation from interaction with beam pipe

➔ GEANT4 (BDSIM)







preliminary setup

Main specifications

1. Measure X and Y by scanning
2. Vacuum
3. Resolution ~ 2 mm (limited by $\delta E/E = 8\ 10^{-4}$)
4. Radiation hard
5. Remote and fast (ns range) readout
6. Signals ~ 10^2 MIPs (Comptons) $\rightarrow$ 10^5 MIPs (halo)

   0.3 pC for 500 μm thick diamond $\rightarrow$ 300 pC

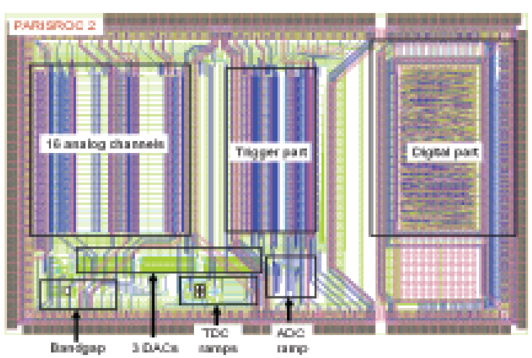
Prototype design of Diamond detector: Front-end electronics

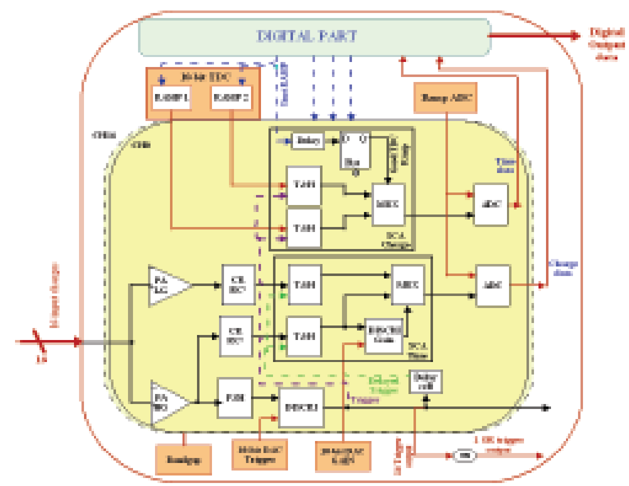
- Front-end electronics : PARISROC2
  - Photomultiplier Array Integrated in SiGe Read Out Chip
  - 16 independent channels and each channel has a variable gain
    ➔ cover the large input dynamic range
  - Charge dynamic range: 50 fC to 100 pC
  - Shaper with variable shaping time (from 25 ns to 100 ns)
  - Self triggering and ADC integrated
  - Both charge and time data can be measured

http://omega.in2p3.fr/

can be expanded up to 500 pC

time resolution ~ 1 ns





Short term ATF2 plan

1. One packaged 4.5 mm2 sCDV diamond sensor from Diamond Detectors Ltd for initial setup and testing
2. Two 4.5 mm2 sCVD diamonds from Element Six Ltd in December
3. Metallisation (Ti/Pt/Au) will provided at GSI in January
4. Electrical (V.I.) test at LAL (Atlas clean room and probe station)
5. Preparation on vacuum compatible ceramic holder (conductive glue, bonding, cabling) by Systrel (groupe Serma, Les Ulis)
6. Charge collection efficiency test at LAL (Atlas clean room with 90sr source and trigger setup)
7. Mechanical design finalization → order micro-mover for vacuum insertion
8. New 100mm beam pipe with 60mm flanges by KEK group
9. Checks with PARISROC2 ASIC test board → produce new board
10. Full check at LAL with 90sr source
11. Installation at KEK and first tests (end of 2013)

SuperB / (SuperKEKB)

SuperKEKB Accelerator

- SuperKEKB is a double-ring, asymmetric energies collider:
  - LER e+ @ 4 GeV, HER e- @ 7 GeV
  - Nano-beam(large Piwinski angle) scheme
  - ***No crab waist at the baseline design***
  - ***No longitudinally polarized electron beam***
  - Target luminosity of 8×10^{35} $cm^{-2}s^{-1}$ at Υ(4S)
  - No realistic consideration for tau/charm threshold so far
- Re-use of KEKB hardware as much as possible
- SuperKEKB DOES NOT consider "Light Source " usage because we think very difficulties of the simultaneous operation.

Y. Ohnishi (KEK, joint bkgd w.s., Feb. 2012

The Superb Accelerator

- SuperB is a 2 rings, asymmetric energies (e^- @ 4.18, e^+ @ 6.7 GeV) collider with:
  - large Piwinski angle and "crab waist" (LPA & CW) collision scheme
  - ultra low emittance lattices
  - longitudinally polarized electron beam
  - target luminosity of 10^{36} cm^{-2} s^{-1} at the $\Upsilon(4S)$
  - possibility to run at τ/charm threshold with L = 10^{35} cm^{-2} s^{-1}
- Design criterias :
  - Minimize building costs
  - Minimize running costs (wall-plug power and water consumption)
  - Reuse of some PEP-II B-Factory hardware (magnets, RF)
- SuperB can also be a good "light source": work is in progress to design Sinchrotron Radiation beamlines (collaboration with Italian Institute of Technology)

Machine Parameters

	SupeKEKB LER	SuperKEKB HER	SuperB LER	SuperB HER	unit
E	4.000	7.007	4.180	6.700	GeV
I	3.6	2.6	2.447	1.892	A
Number of bunches	2,500		978		
#Particles/bunch	9.04	6.53	6.56	5.08	10^{10}
Circumference	3,016.315		1,258.400		m
$\varepsilon_x / \varepsilon_y$	3.2(1.9)/8.64(2.8)	4.6(4.4)/11.5(1.5)	2.46(1.82)/6.15	2.0(1.97)/5.0	nm/pm
Coupling	0.27	0.28	0.25	0.25	
β_x^* / β_y^*	32/0.27	25/0.30	32/0.205	26/0.253	mm
Crossing angle	83		66		mrad
α_p	3.25	4.55	4.05	4.36	10^{-4}
σ_δ	8.08(7.73)x10^{-4}	6.37(6.31)x10^{-4}	7.34x10^{-4}	6.43x10^{-4}	
V_c	9.4	15.0			MV
σ_z	6.0(5.0)	5(4.9)	5.0(4.29)	5.0(4.69)	mm
ν_s	-0.0247	-0.0280	-0.0129	-0.0135	
ν_x / ν_y	44.53/44.57	45.53/43.57	42.575/18.595	40.575/17.595	
U_0	1.87	2.43	0.865	2.11	MeV
$\tau_{x,y} / \tau_s$	43.1/21.6	58.0/29.0	40.6/20.3	26.7/13.4	msec
ξ_x / ξ_y	0.0028/0.0881	0.0012/0.0807	0.0033/0.0971	0.0021/0.0970	
Luminosity	8×10^{35} (P_{tot} = 71 MW)		10^{36} (P_{RF} = 17 MW)		$cm^{-2}s^{-1}$

Luminosity operational mode & backgrounds / MDI design dominated by several beam loss processes

Y. Funakoshi (KEK, joint bkgd w.s., Feb. 2012

	LER beam lifetime
Touschek effect	~10 min.
Beam-Gas Coulomb scattering	~30 min.
Radiative Bhabha	~30 min.

ee→ eeee process (pair bkdg in VD)

Lifetime summary

	HER	LER
Touschek lifetime	τ_{TOU} (min)	τ_{TOU} (min)
No collimators, nominal ε_x (no IBS)	26	7.4
No collimators, ε_x with IBS	26	10.2
With Collimators, ε_x with IBS	22	7
Coulomb	50 min	39 min
Bremsstrahlung	72 hrs	77 hrs

IR rates summary

|s|<2 m

Touschek	HER	LER
No collimators, ε_x with IBS	2.4 GHz	17 GHz
With Collimators, ε_x with IBS	**6.8 MHz**	**72 MHz**

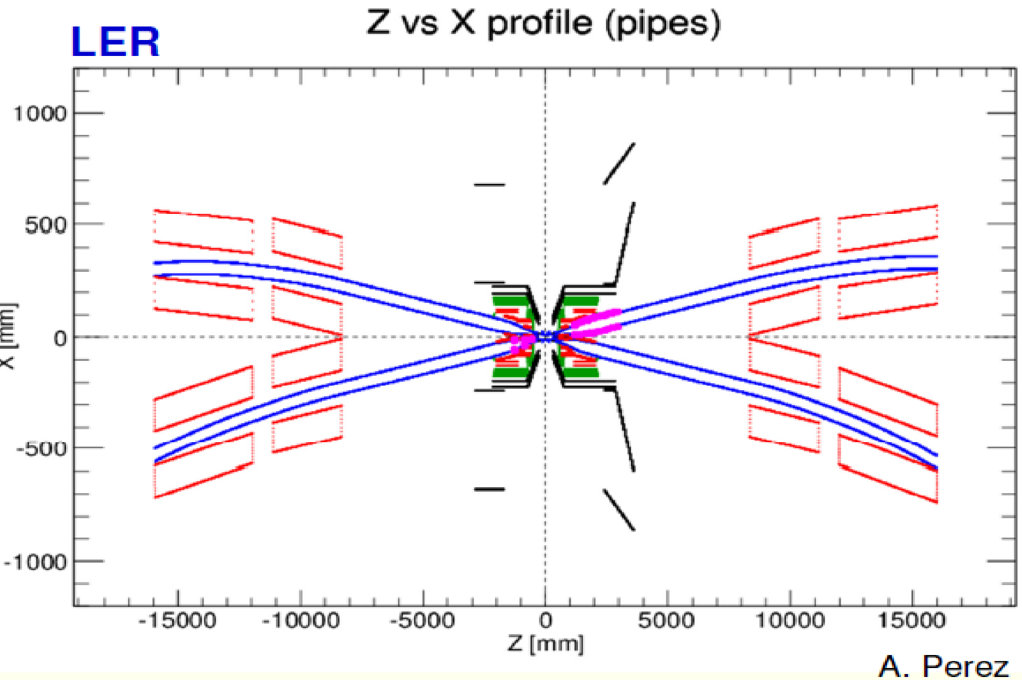
M. Boscolo (LNF, SuperB meeting, March 2012

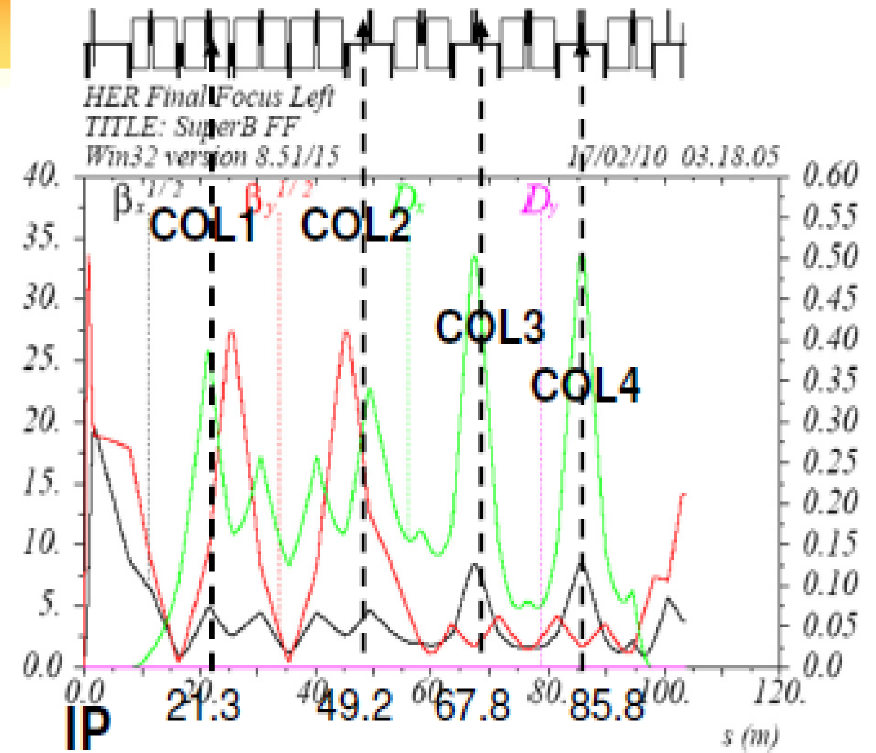
	HER	LER
Coulomb No collimators, ε_x with IBS	10.5 GHz	25 GHz
Coulomb with collimators, ε_x with IBS	**3.7MHz**	**36 MHz**
Bremsstrahlung with coll	130KHz	450KHz

Table 9.5: Bhabha (radiative and elastic) beam lifetimes for several SuperB options.

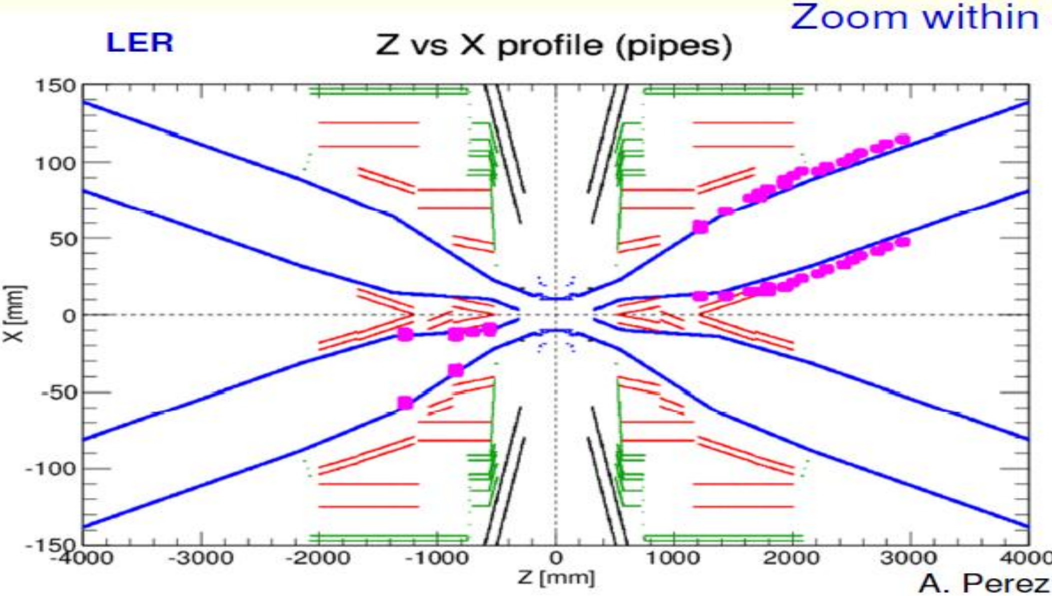
	Base Line		Low Emittance		High Current	
	HER	LER	HER	LER	HER	LER
τ (min)	4.6	5.6	3.6	4.3	7.5	9.2

Touschek particles hitting the pipe: full geometry before tracking



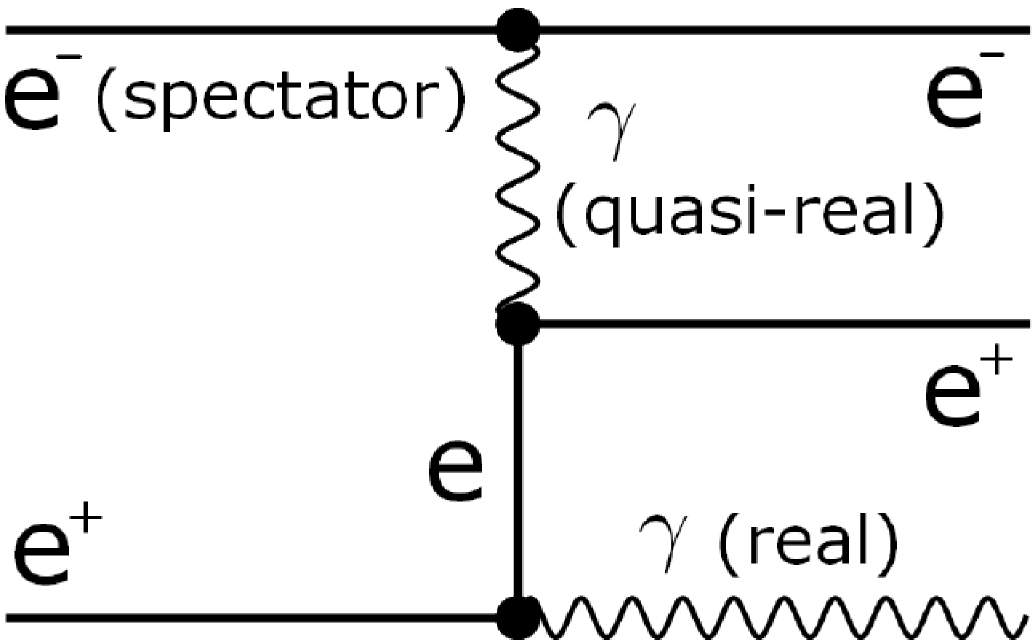


Zoom within 4 m



Check for any Touschek or beam gas scattering losses in candidate areas for fast luminosity monitoring

Radiative Bhabha ("Compton") process

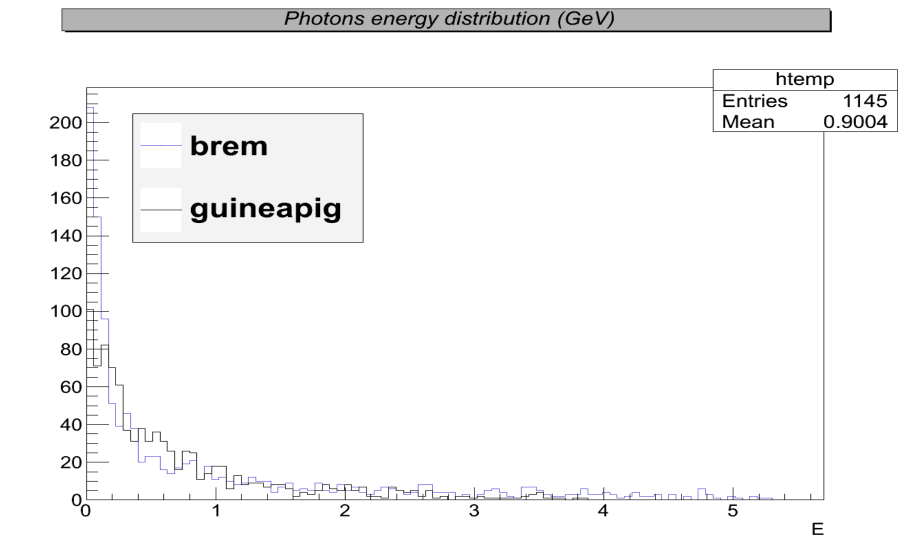


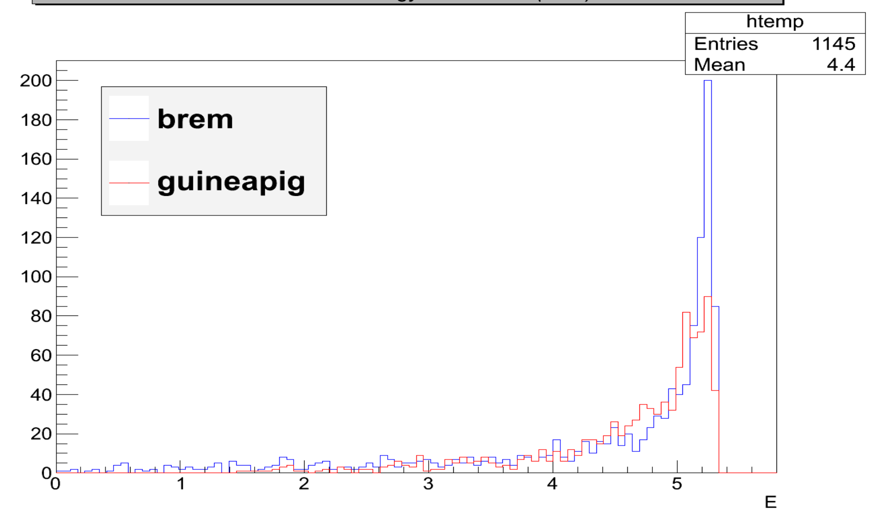
Represents major background source via particle loss after IP

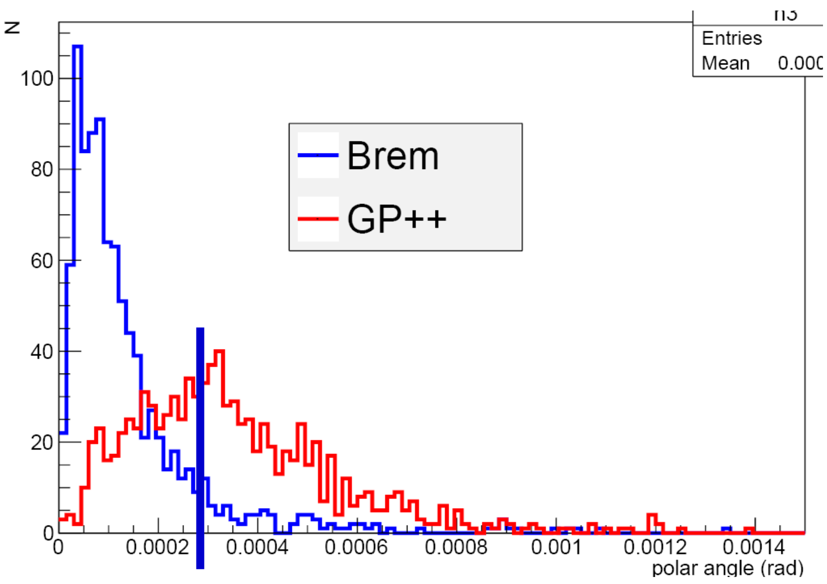
can be used for luminosity monitoring

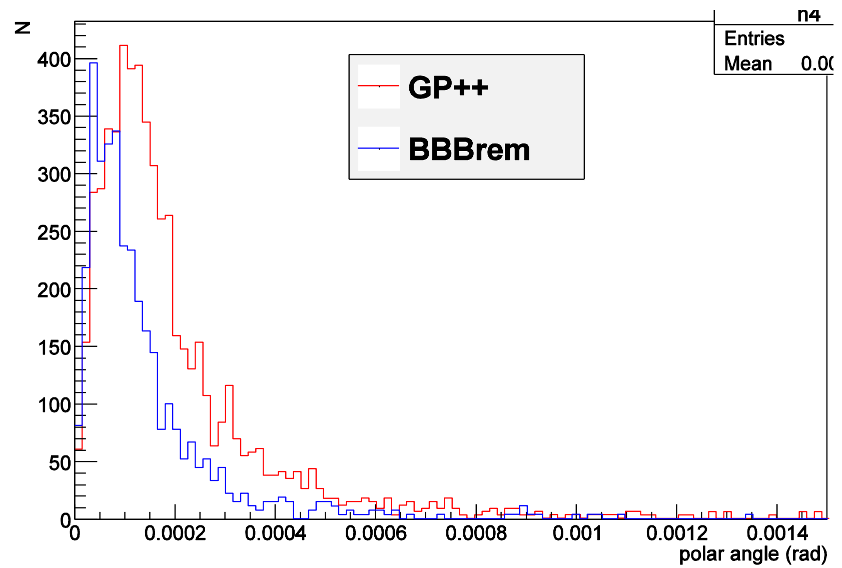
$\sigma \sim 250$ mbarn ($E_\gamma > 1\%\ E_{beam}$)

Different EPA factorization methods



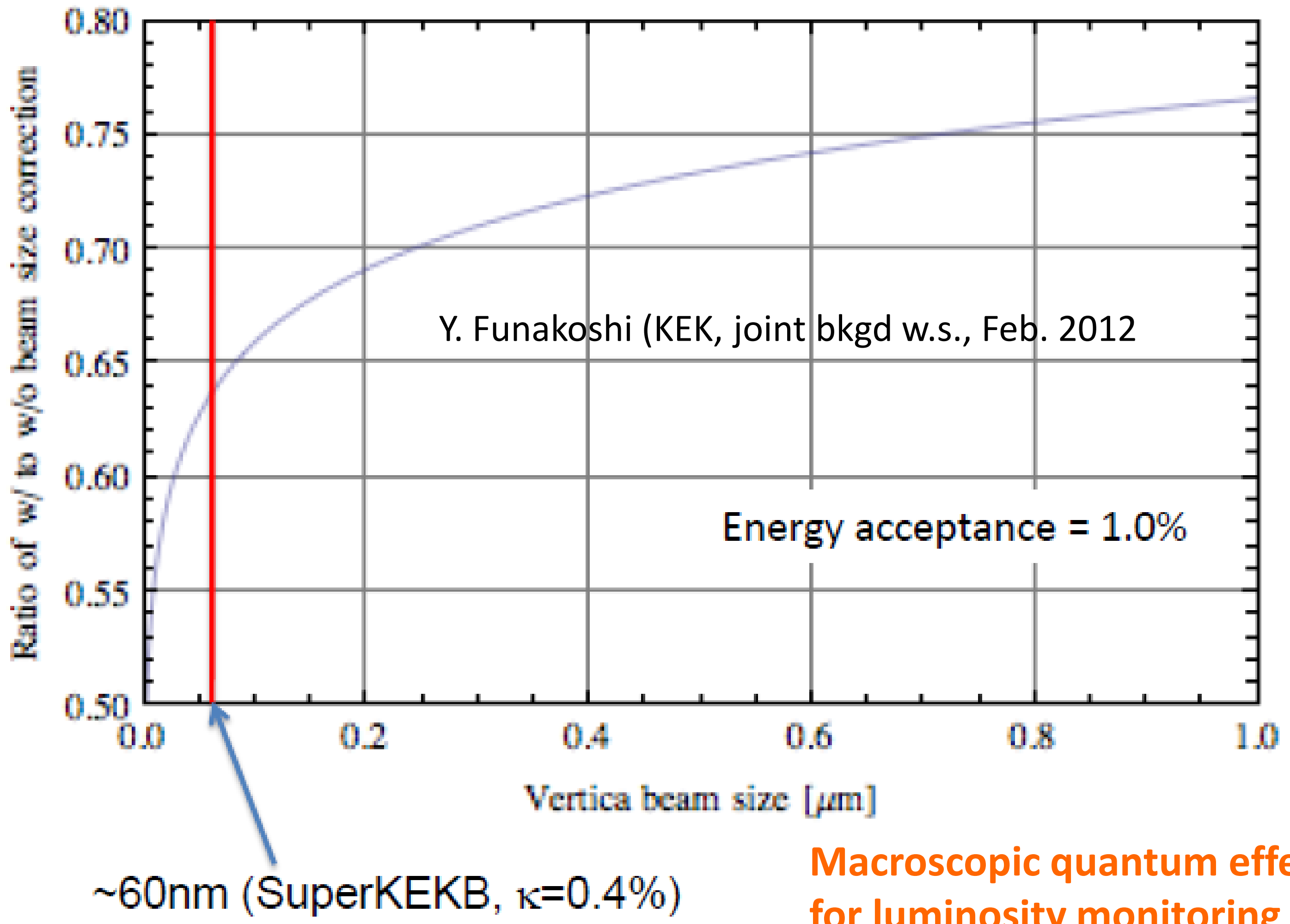






$\sigma_x^{beam} \sim 0.3$ mrad

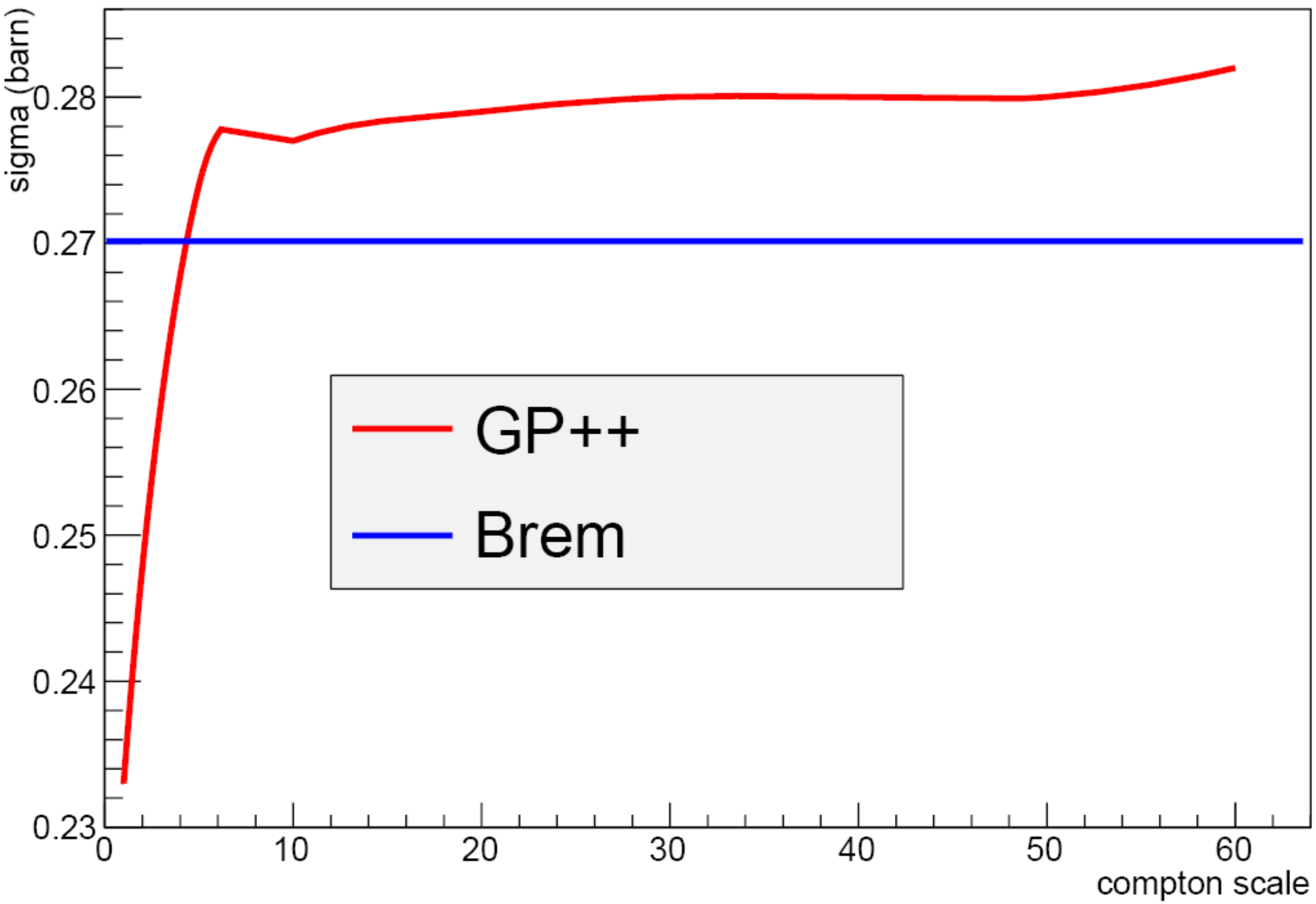
Correction for cross section due to finite beam size



Macroscopic quantum effect... issue for luminosity monitoring ?

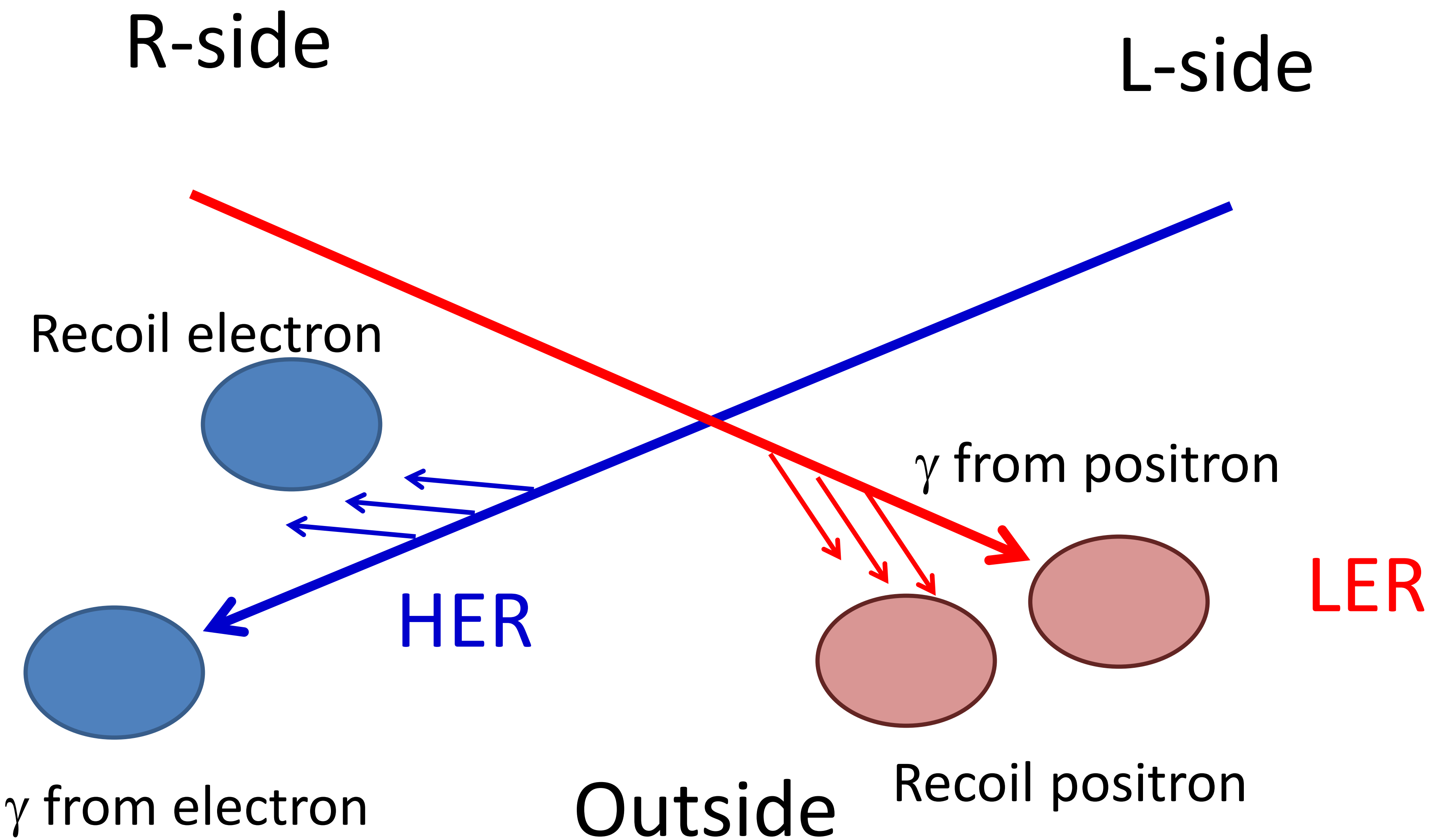
Cross section

beam size effect ON in GP++

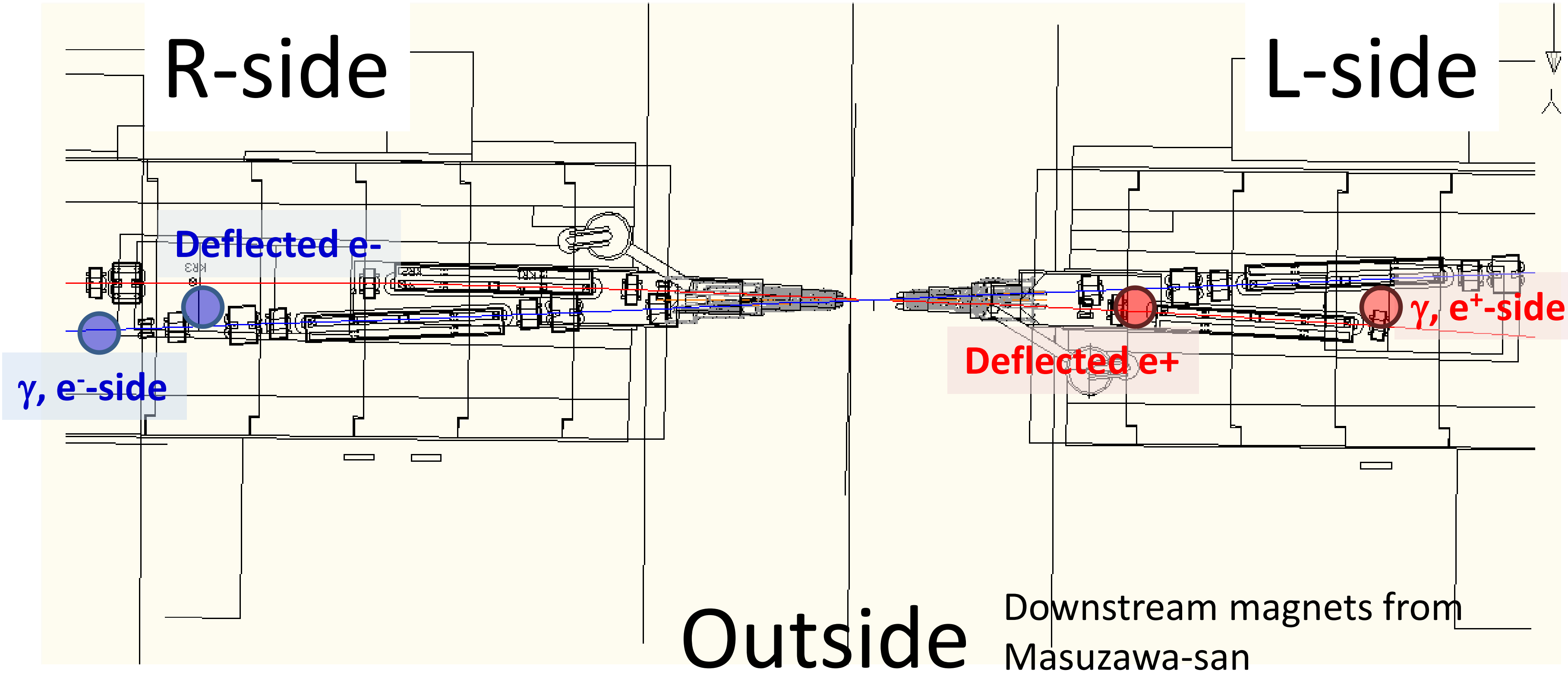


For compton_scale = 1, σ_{BBBrem} = 0.270 barn and σ_{GP} = 0.23 barn: 15% difference
From compton_scale ~ 10, σ_{GP} = 0.28 barn so 3.5% difference
➔Not exactly the same but a sufficient precision on σ for our study

Where are the signals?



Possible locations



Possible problems:

Material quantity of the beam chamber in r.l.

Undesirable sensitivity to angle and position/size of the beams at IP

Specifications and rates

1. average luminosity
2. bunch by bunch luminosity

Ground motion analysis and experience from Belle & PEP-II

Relative accuracy $<10^{-3}$ at 0.1-1 kHz

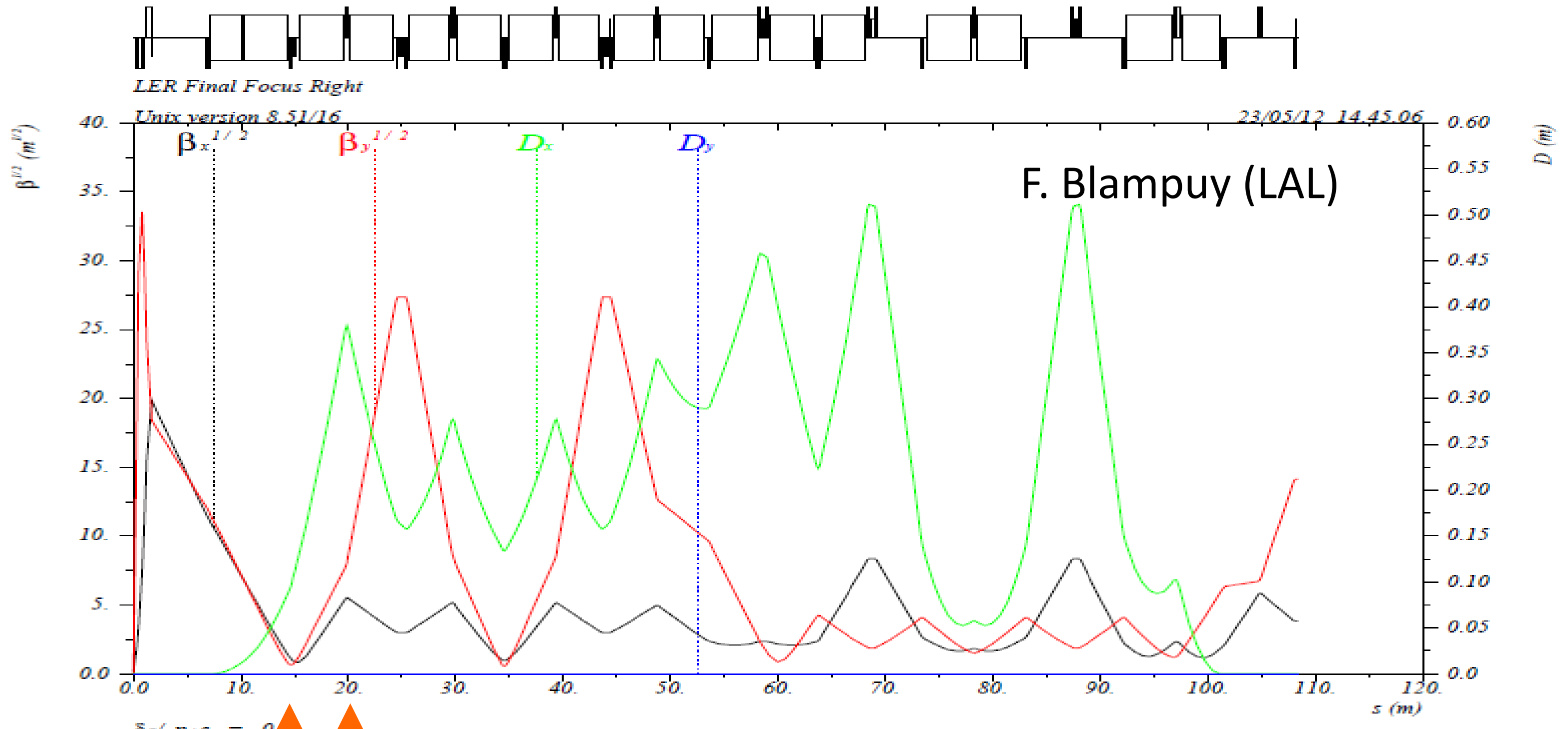
Detected particles $>10^{6}$ at 0.1-1 kHz

$L \sim 10^{36}\ cm^{-2}s^{-1}$

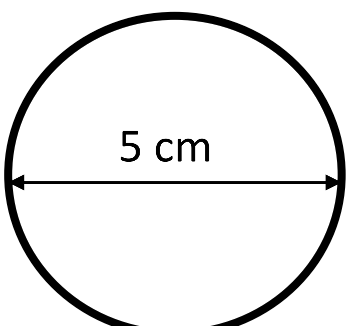
$\sigma \sim 250$ mbarn ($E\gamma > 1\%$ Ebeam) ➔

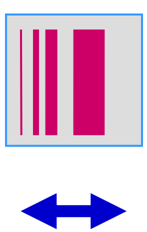
expected total rate $\sim 250\ 10^{6}$ / 0.001 s

- Must also work for lower initial luminosities: 10^{2-4} dynamic range
- Non luminosity scaling contamination (e.g. from Touschek and beam gas Coulomb losses) < 1%



2 first candidate locations in SuperB LER





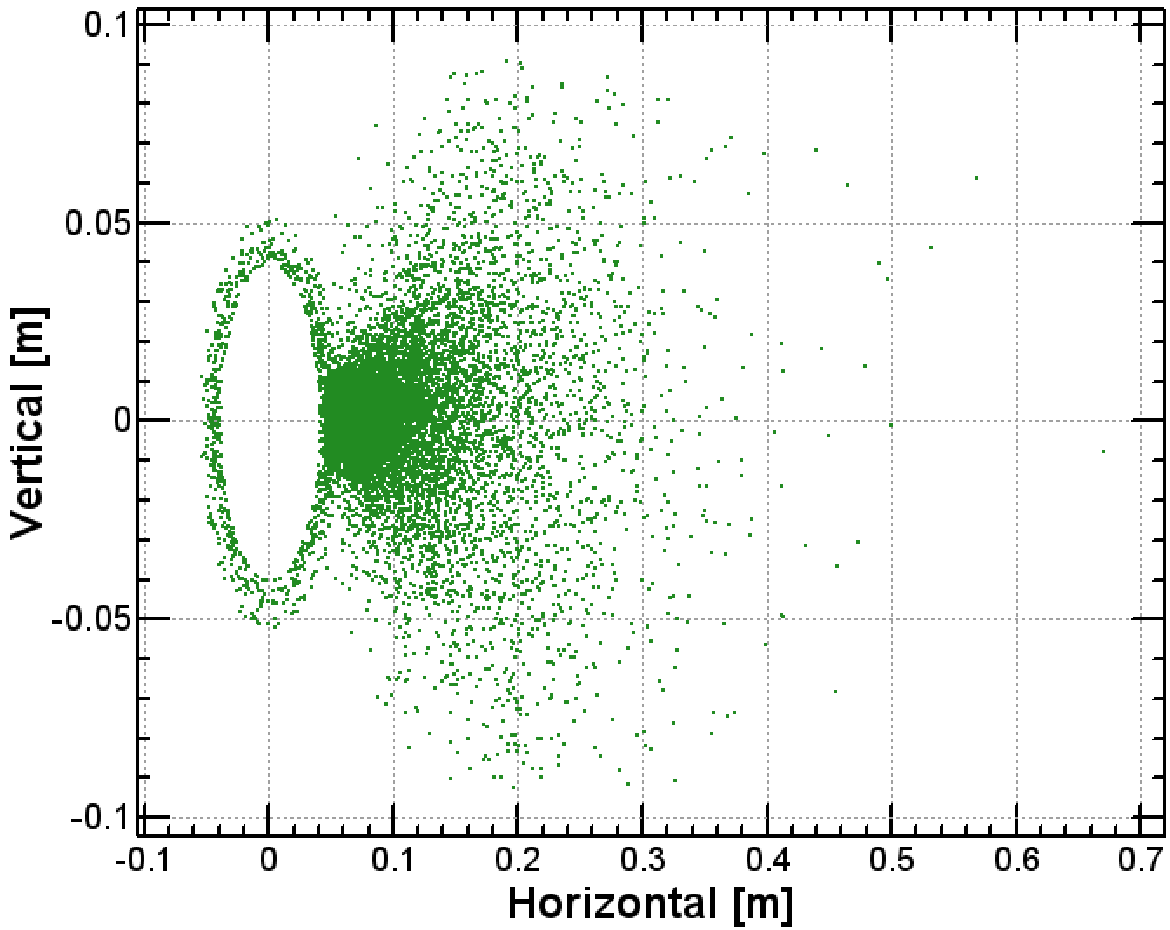
Estimated counting rate in 5 × 5 mm^2 **sensor** placed 3.5 cm from beam ~ 5 10^6 / 0.001 s

Estimated dose ~ up to 20 MGy / year of 10^7 s

sCVD diamond radiation resistant (up to ~ 10 MGy)

Mechanical adjustment and / or structured metallisation with variable size strips on one face to provide a suitable dynamic range

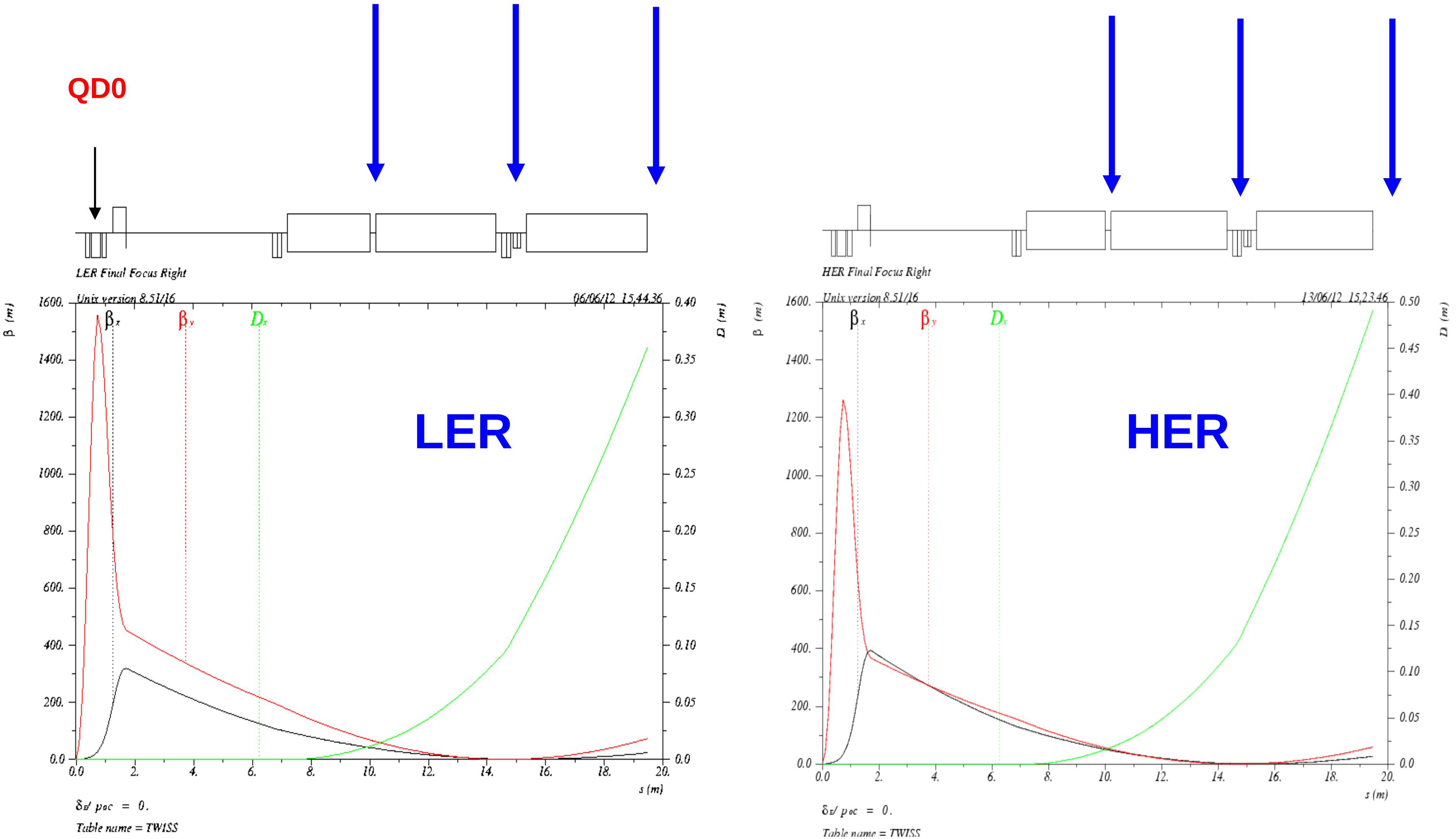
Loss pointの座標（transverse）



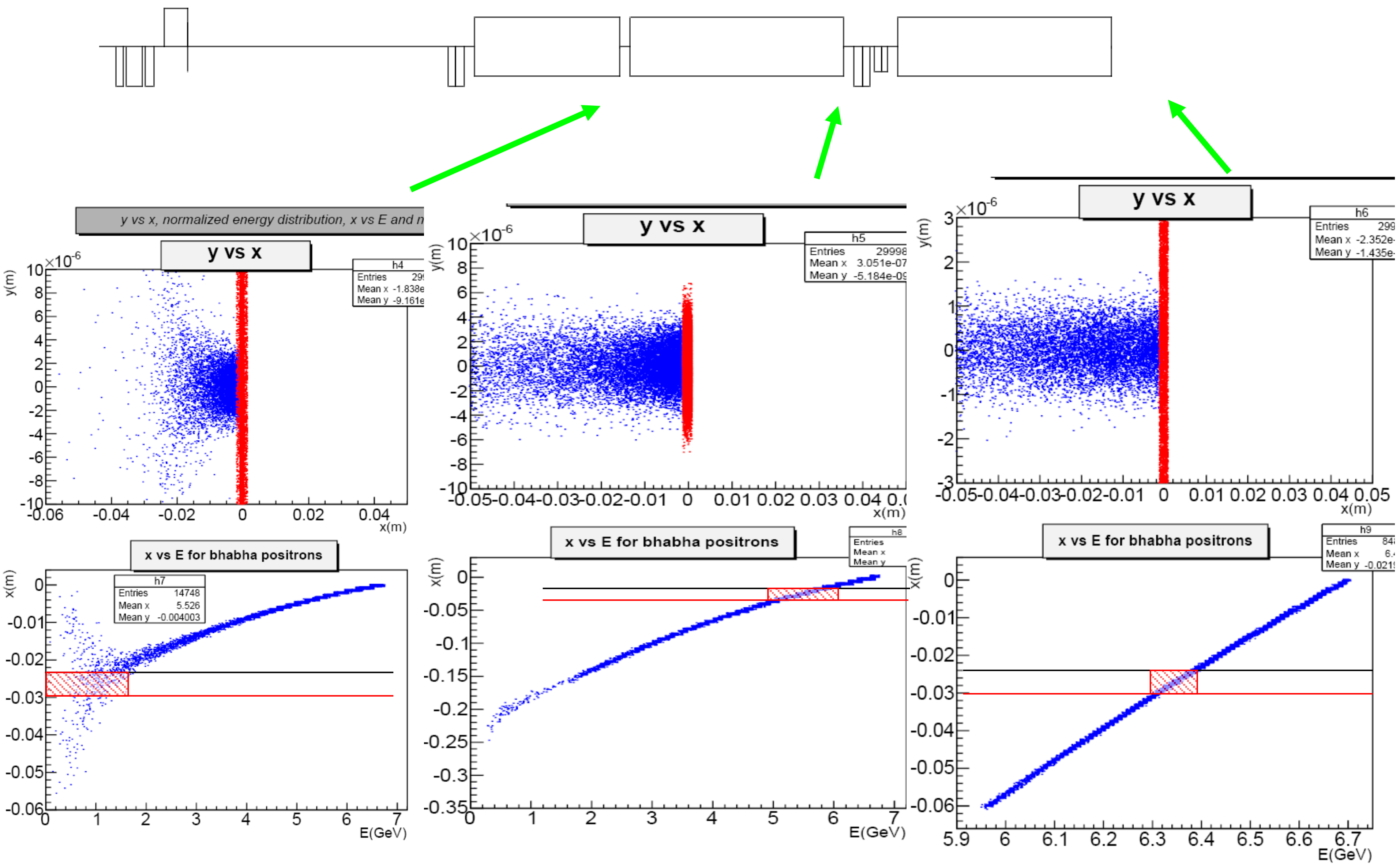
4m < s < 16m (sはIPからの距離)

Y. Funakoshi (KEK)

Best locations to maximise Bhabha / Touschek & beam gas rates



Distribution of scattered Bhabha positron



Estimation of the fraction of Bhabha particles generated with GP++ in the sensor acceptance

	Without apertures in MAD8 (5X5mm diamond sensor)	With apertures in MAD8 (5X5mm diamond sensor)	With apertures in MAD8 (horizontal length of 10mm)
1‰ specification at L_{nom} ($10^6/N_{Bhabha}$ produced)		3.10^{-3}	
1‰ specification at $L_{nom}/10^2$		3.10^{-1}	
1% specification at $L_{nom}/10^2$ ($10^4/N_{Bhabha}$ produced)		3.10^{-3}	
LER: $N_{Bhabha\ detected}$ / 15188 après le 1st bend	$3,23.10^{-3}$	$1,98.10^{-3}$	$2,90.10^{-3}$
LER: $N_{Bhabha\ detected}$ / 15188 after the 2nd bend	$2,83.10^{-2}$	$2,87.10^{-2}$	$5,33.10^{-2}$
LER: $N_{Bhabha\ detected}$ / 15188 after the 3rd bend	$4,58.10^{-2}$	$4,56.10^{-2}$	$5,16.10^{-2}$
HER: $N_{Bhabha\ detected}$ / 14911 aftere the 1st bend	$7,18.10^{-3}$	$9,99.10^{-3}$	$1,23.10^{-2}$
HER: $N_{Bhabha\ detected}$ / 14911 after the 2nd bend	$3,48.10^{-2}$	$3,41.10^{-2}$	$6,18.10^{-2}$
HER: $N_{Bhabha\ detected}$ / 14911 after the 3rd bend	$4,39.10^{-2}$	$4,40.10^{-2}$	$4,97.10^{-2}$

Short term SuperB plan

- Implement sensor in GEANT4 “IR +/- 21 m” for scattered electron/positron (on-going)
- Optimize vacuum chamber geometry (impedance constraint)
- Input to optics lattice and magnet design
- Touschek and beam gas rates at sensor location to limit non-luminosity scaling (on-going)
- Design of sensor / readout prototype for DAPHNE (or ATF) test

Longer term

- Further study of scattered photon detection
- Radiation hardness
- Bunch by bunch luminosities (specification, requirements,…)
- Feedback methods (dither method, calibration,…)
- Beam size effect

LAL group resources

Contributors:
P. Bambade, C. Rimbault, S. Liu (PhD), I. Khvastunov (Master), Stefano Tammaro (Master), F. Bogard & S. Wallon (mech. eng.), S. Conforti (FE elec. eng.),

Pending applications / t.b.c. :
Post-doc, XX (sensor tech. eng.), PhD student

Budget: P2IO LABEX grant, IN2P3, France-Japan bilateral funds