Diamond sensor for beam halo monitoring & collimation

On-going work and plan for ATF2

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On behalf of and collaborating with:

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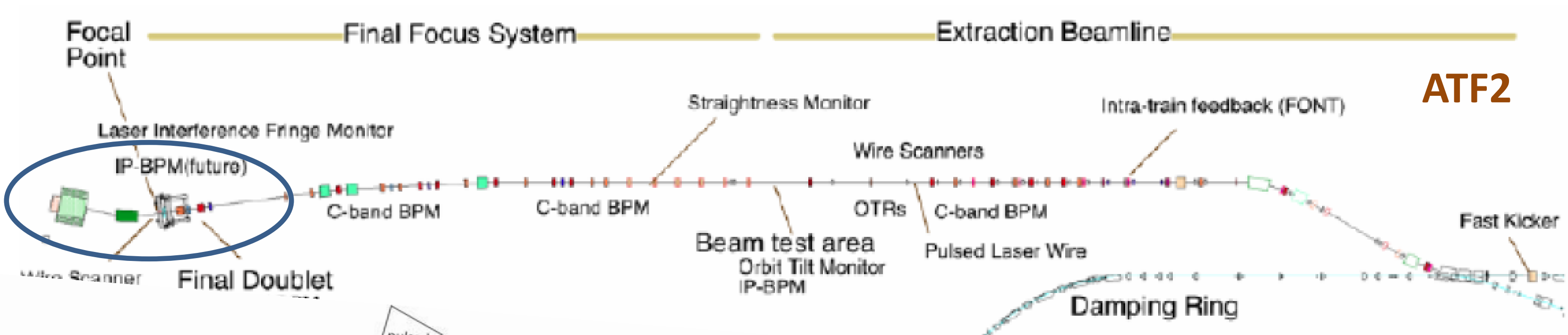
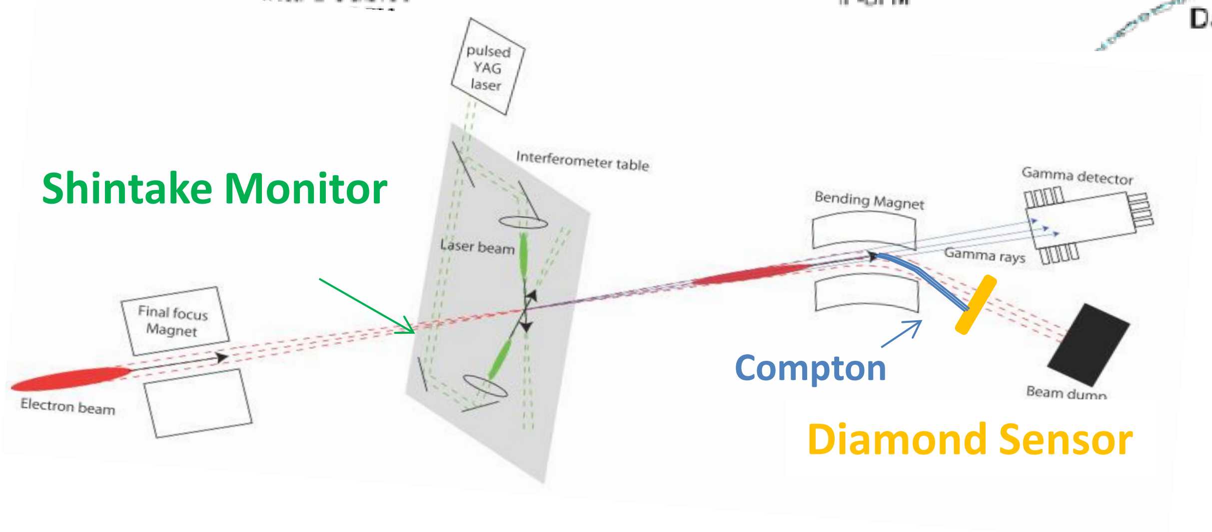
LCWS13 **Tokyo, 11-15 November 2013**

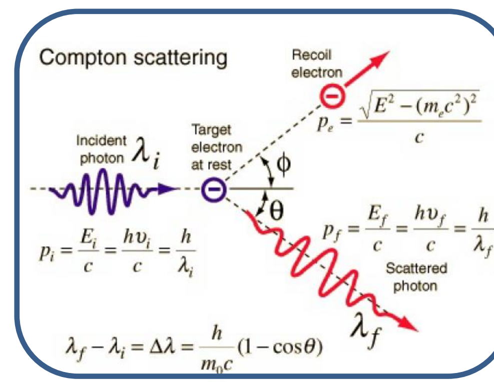
Topics

- Beam halo ⇔ BSM background
  - measurement
  - collimation
  - modeling halo formation and re-generation
- Diamond sensor to measure beam halo and tails
  - features of diamonds
  - beam testing at PHIL (low energy photo-injector beam at Orsay)
  - design of in-vacuum diamond scanner for ATF2 and PHIL

Introduction







Motivations:

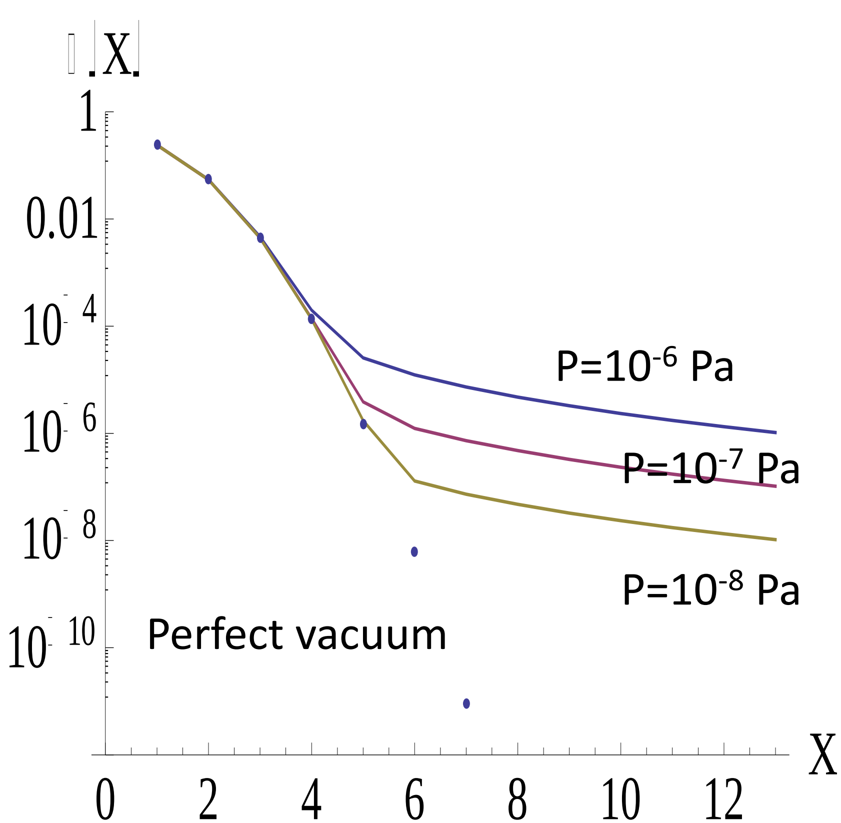
- ***Beam halo transverse distribution unknown → investigate halo model & propagation***
- ***Monitor beam halo to control backgrounds by means of collimation and tuning***
- ***Probe Compton recoil electron→ (possibly, in future, higher order contributions)***

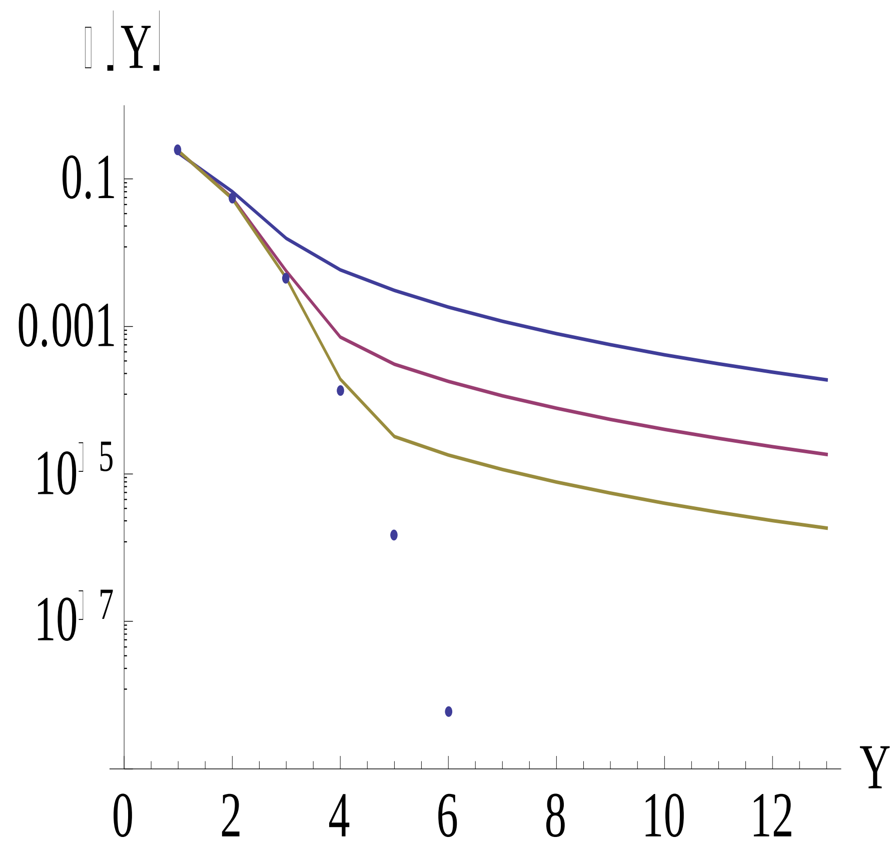
Analytical and simulation modeling of ATF beam halo shape:

- beam gas scattering
- beam gas bremstrahlung
- intra-beam scattering

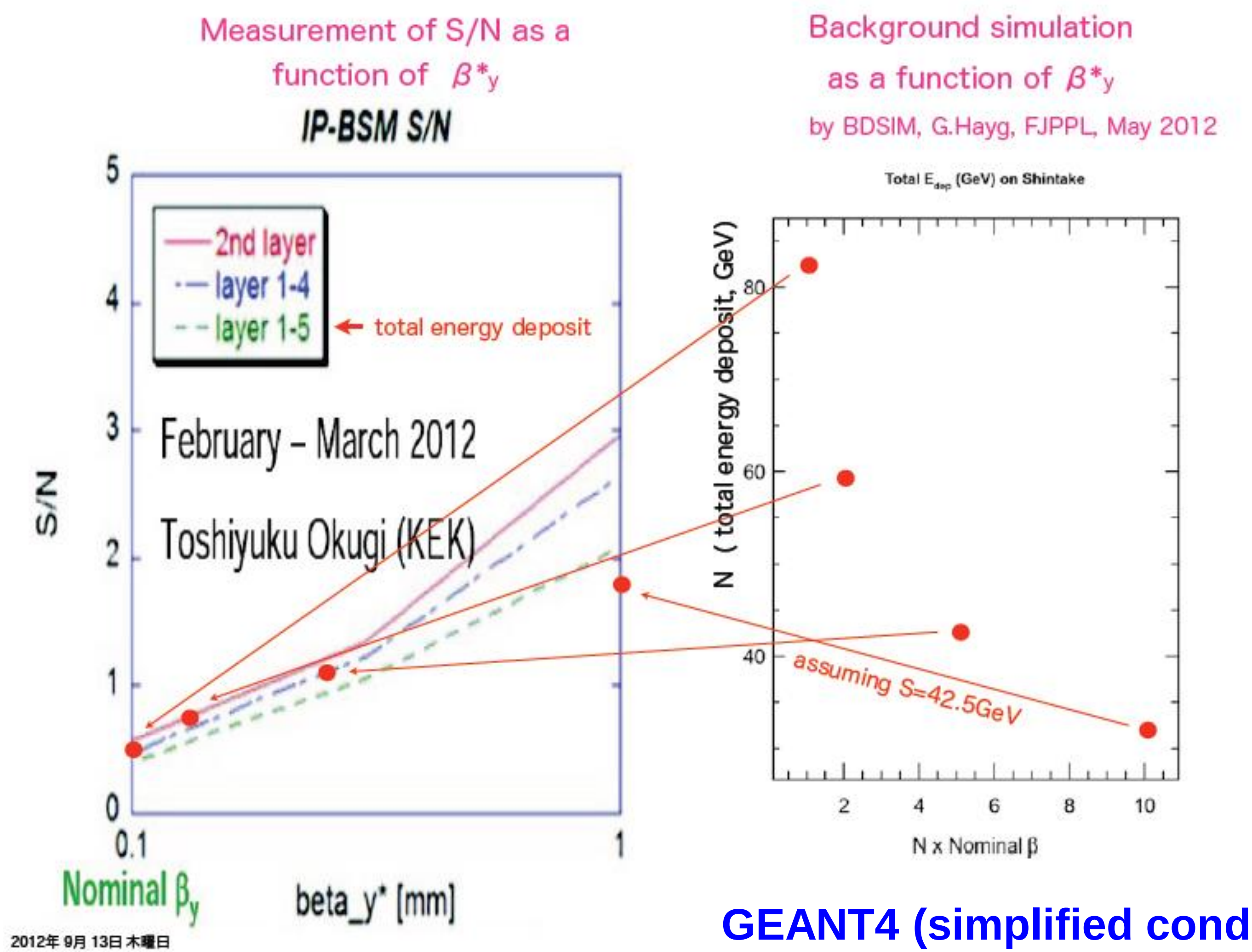
Dou Wang (IHEP)

Ex.: horizontal and vertical halo distribution from beam-gas scattering





Beam halo and BSM background issues



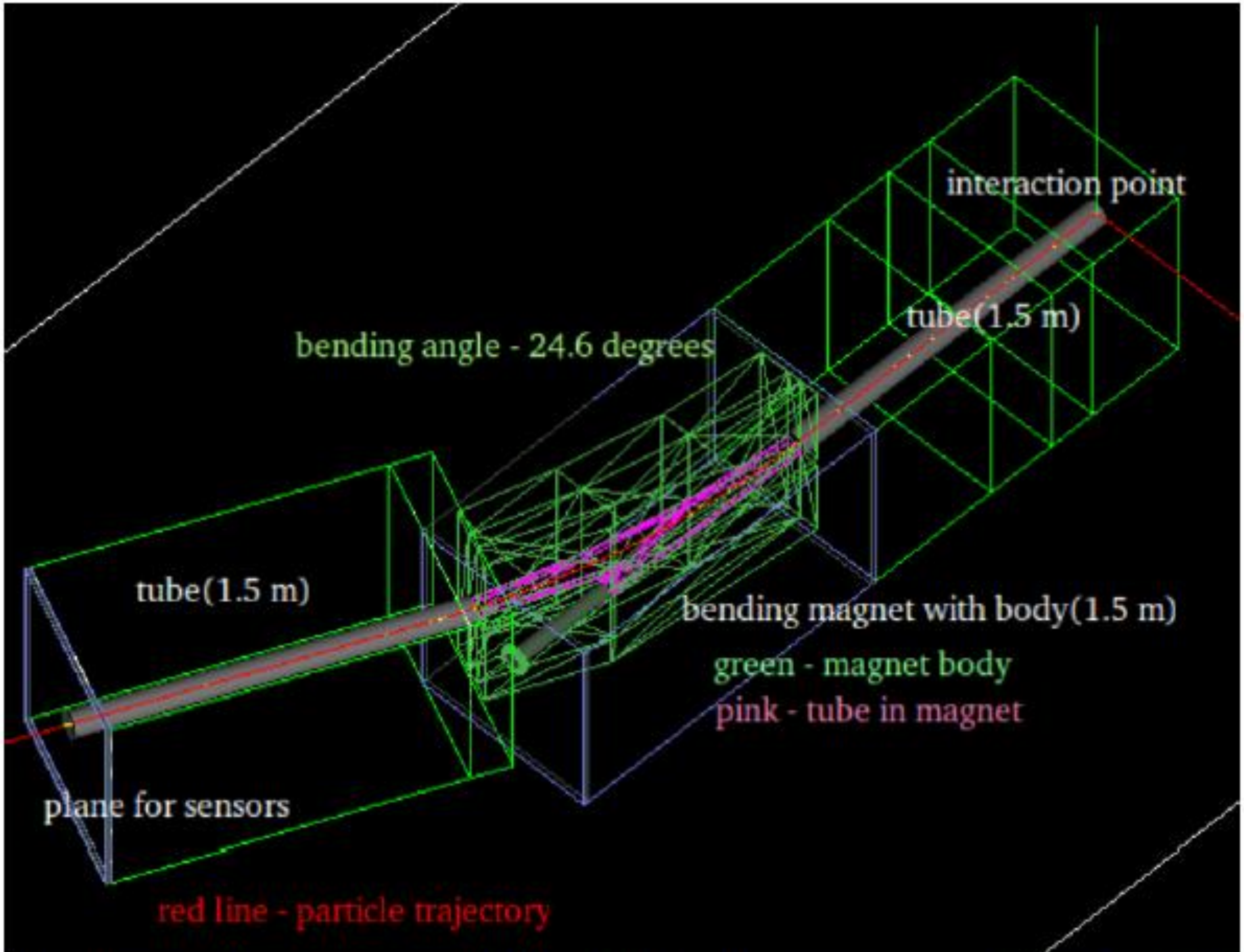
GEANT4 (simplified conditions)

Halo intercepted on

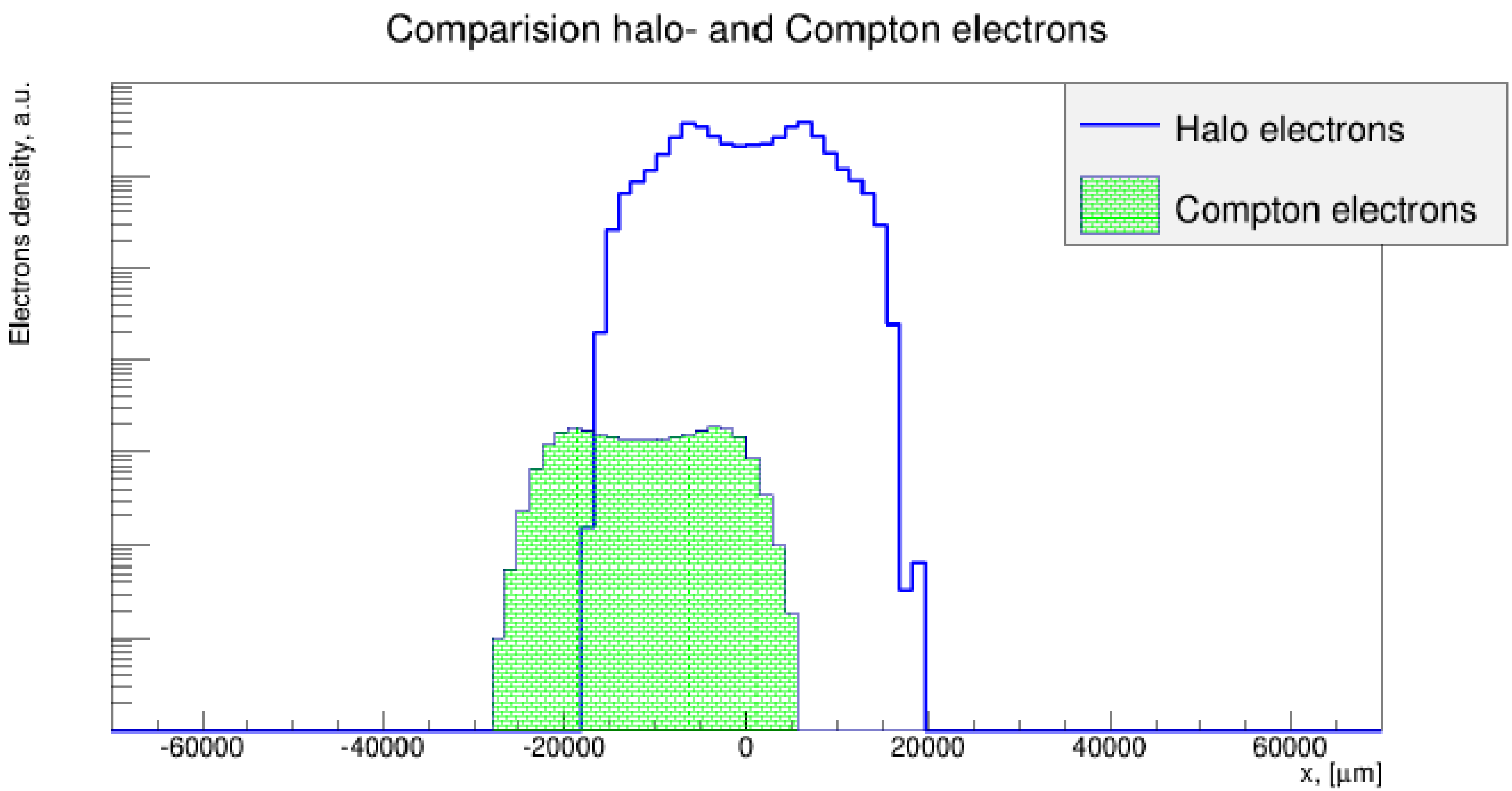
- **post-IP bend magnet vertical gap**
- **final doublet beam pipe**
- **chromatic correction c-band / ref. BPMs**

under study…

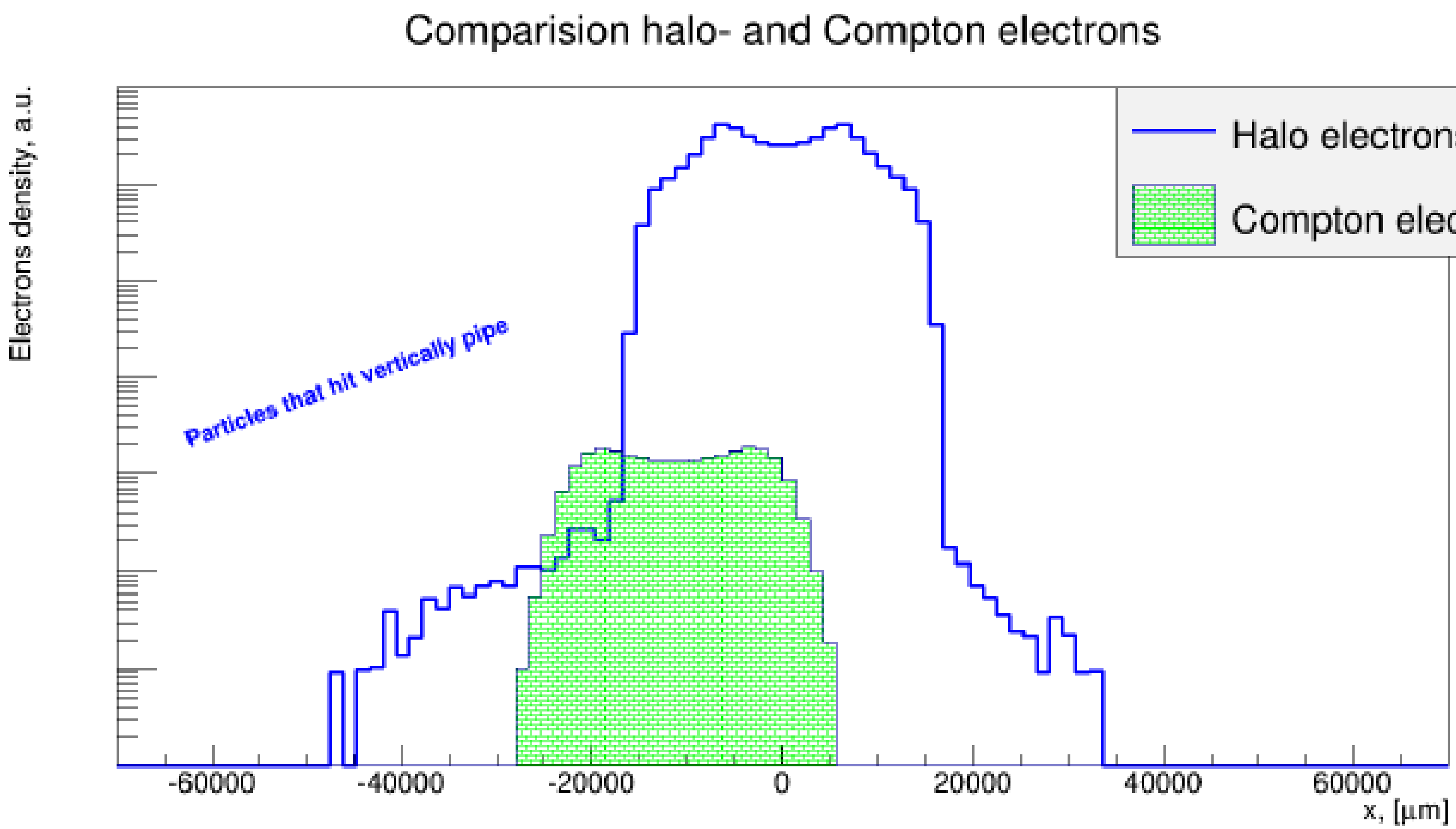
Considering system in simulation



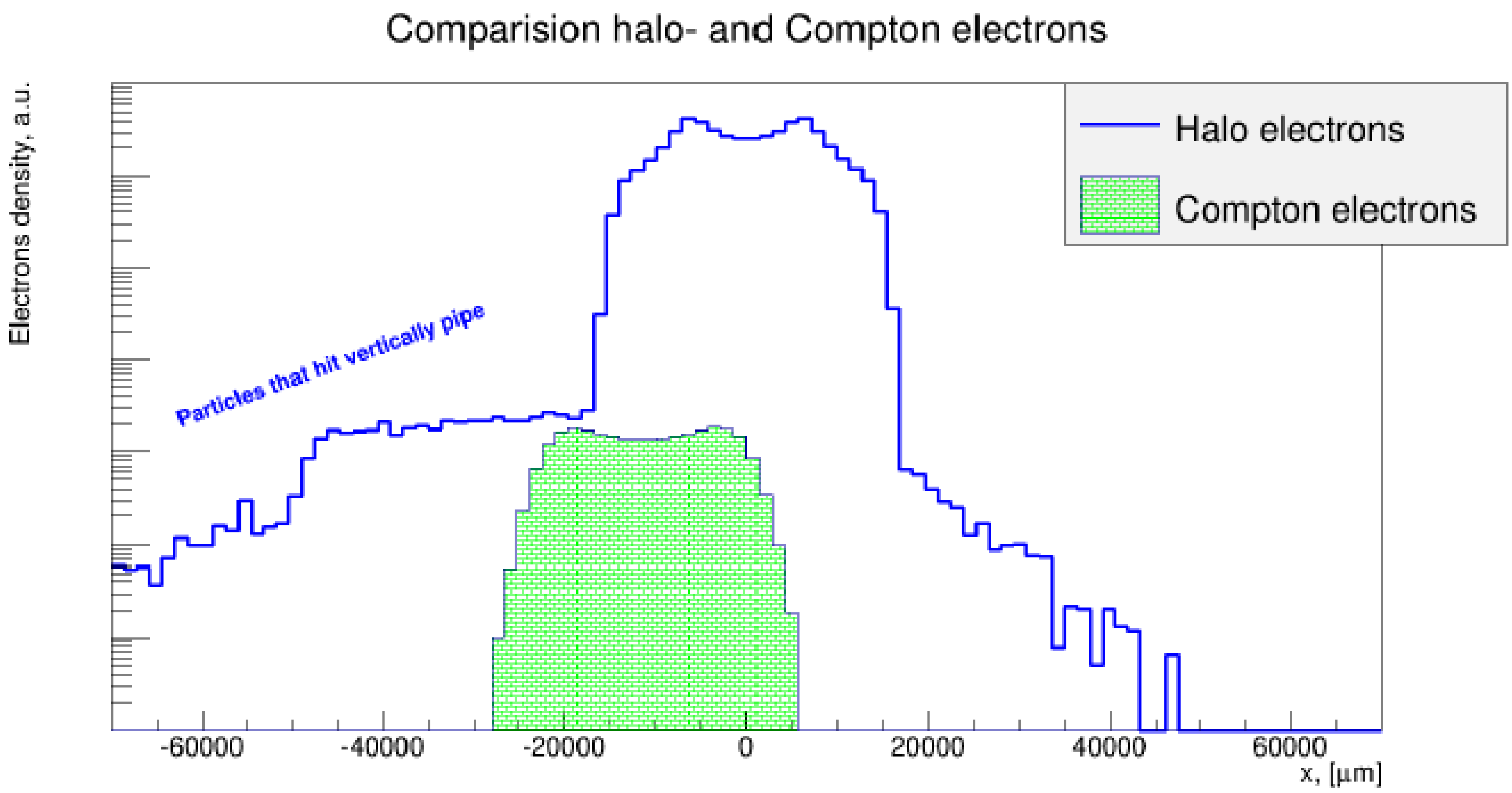
7.5 σ_{xp} and $7\sigma_{yp}$



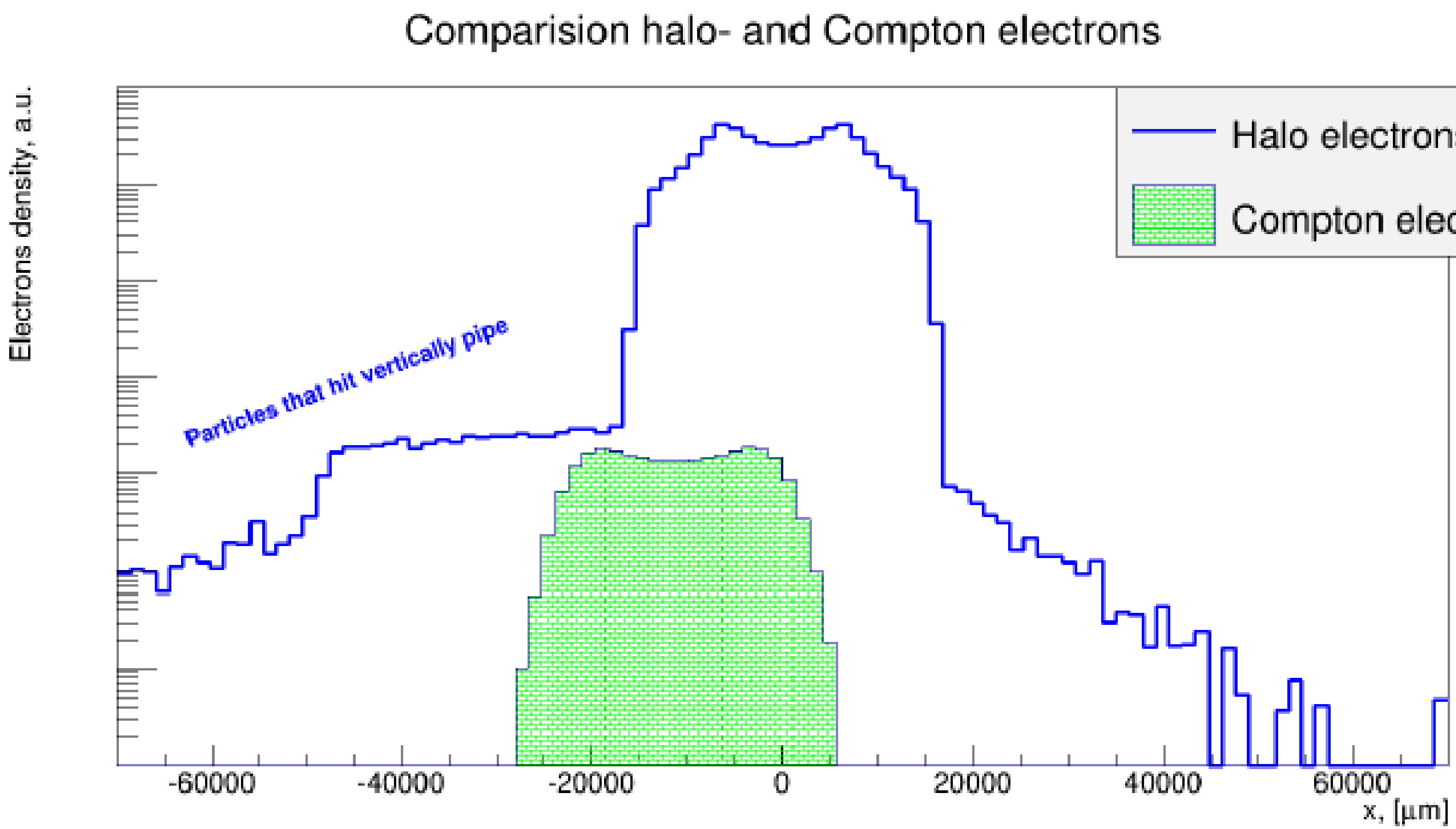
7.5 σ_{xp} and $15\sigma_{yp}$



7.5 σ_{xp} and 20σ_{yp}



7.5 σ_{xp} and $30\sigma_{yp}$



Present "collimator" used at ATF2 = tapered beam pipe between QD10BFF and QD10AFF

Beam size at QD10BFF:

σ_y = 328.85 um (in simulation)

Beam pipe radius: R= 8mm

Beam pipe should cut the beam at:

$R/\sigma_y \approx \pm 24\ \sigma$

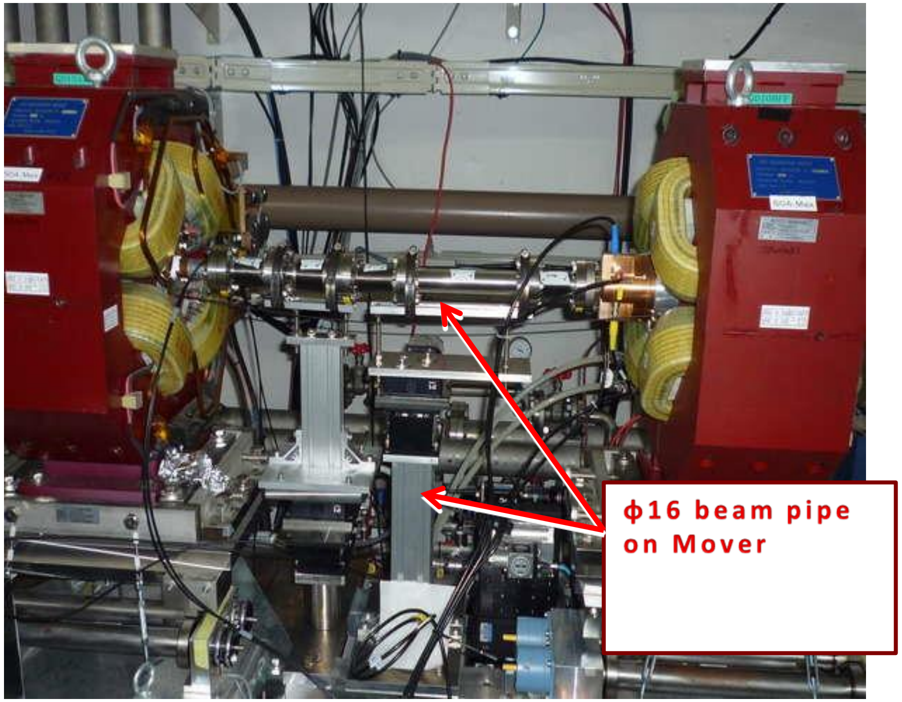
Post IP wire scanner (MPIP): 70 cm from IP

Beam size at MPIP :

σ_s = 235.6 um (in simulation)

Measured beam size at MPIP:

σ_m = 308.9 um (in measurement)

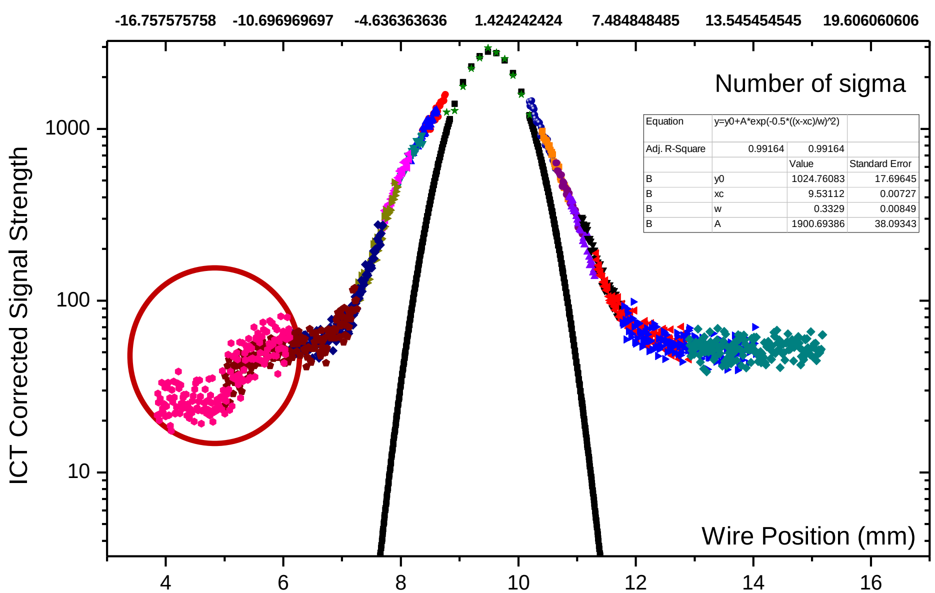


Factor for betatron mismatch: $k = \sigma_s / \sigma_m = 0.76$

⇨ **Predicted edge of cut at :** $24\ \sigma * k \approx \pm 18\ \sigma$

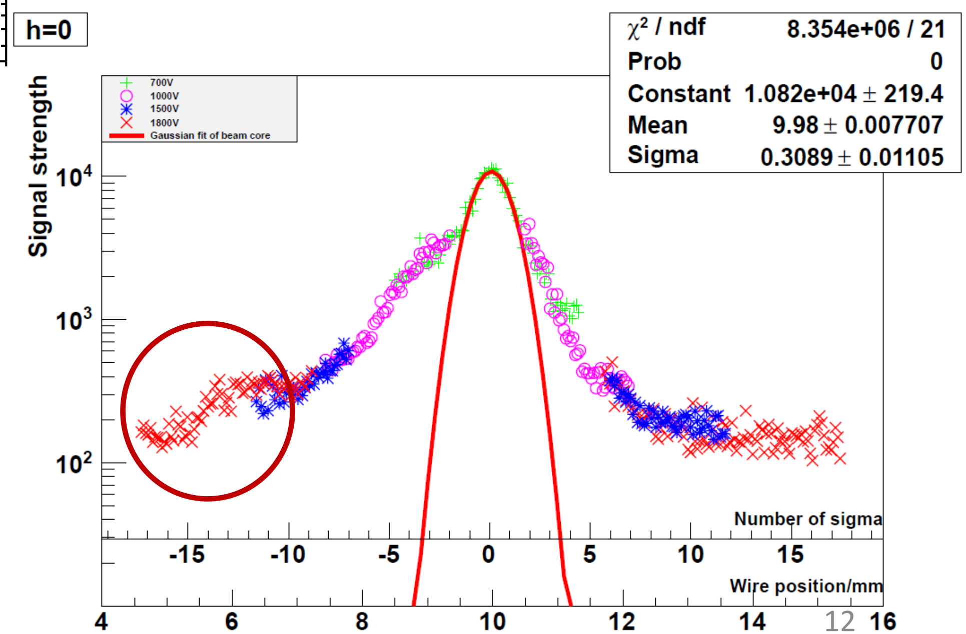
Halo Distribution at Post-IP

Sha Bai (IHEP), Shan Liu (LAL)



→ Data taken in April 2013

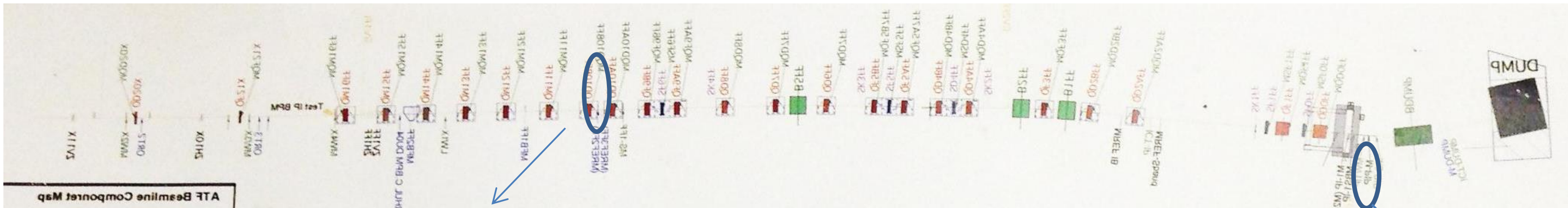
Data taken in June 2013 ←

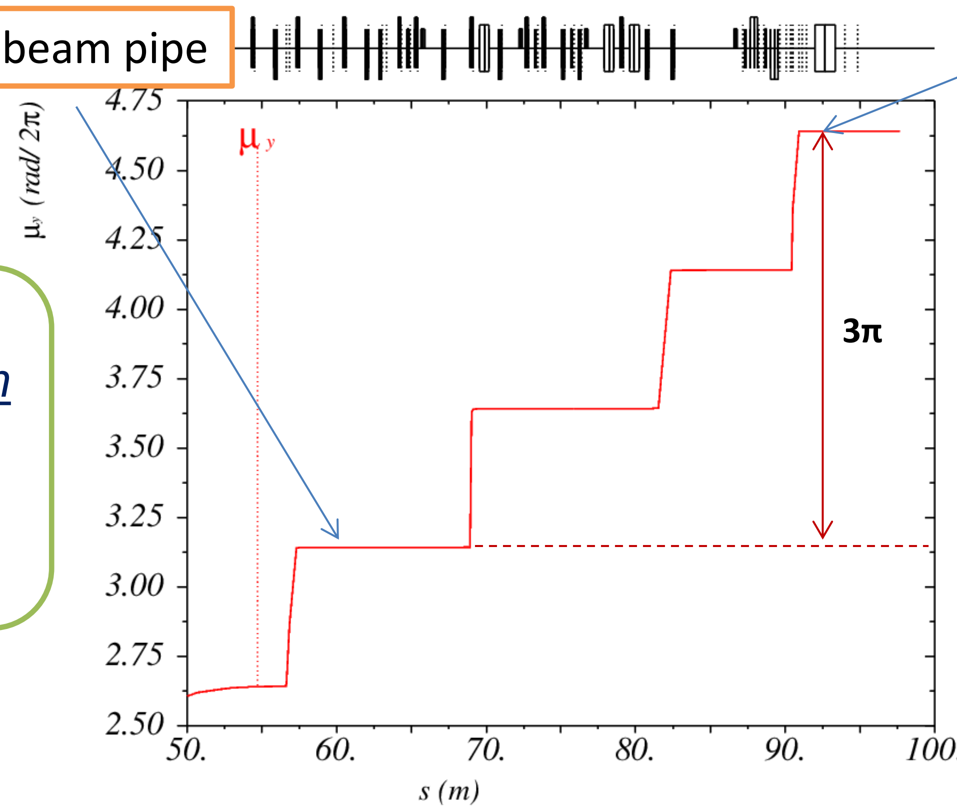


Edge of cutting almost at the same position -> -14σ

-> Beam was not centered?

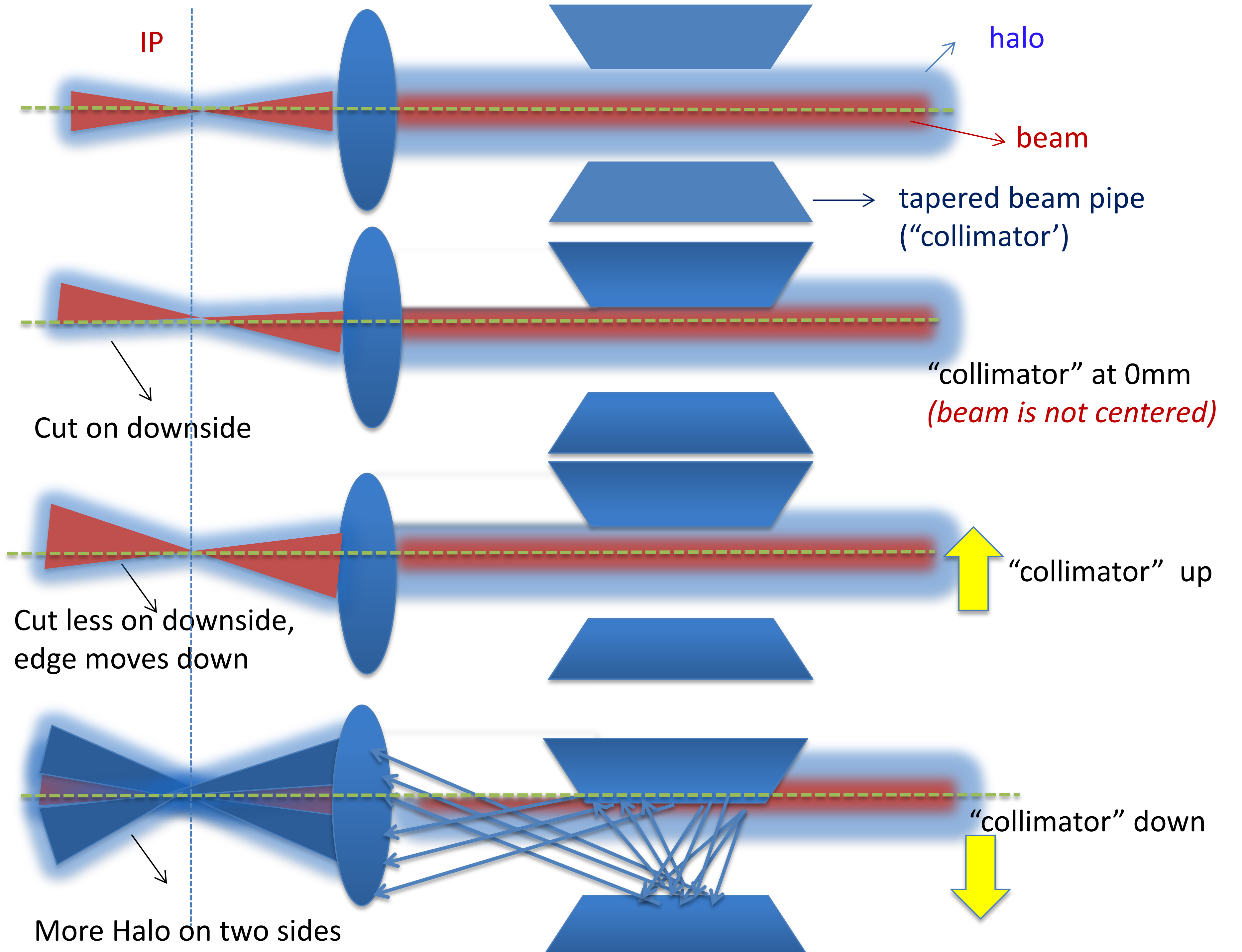
Phase Difference





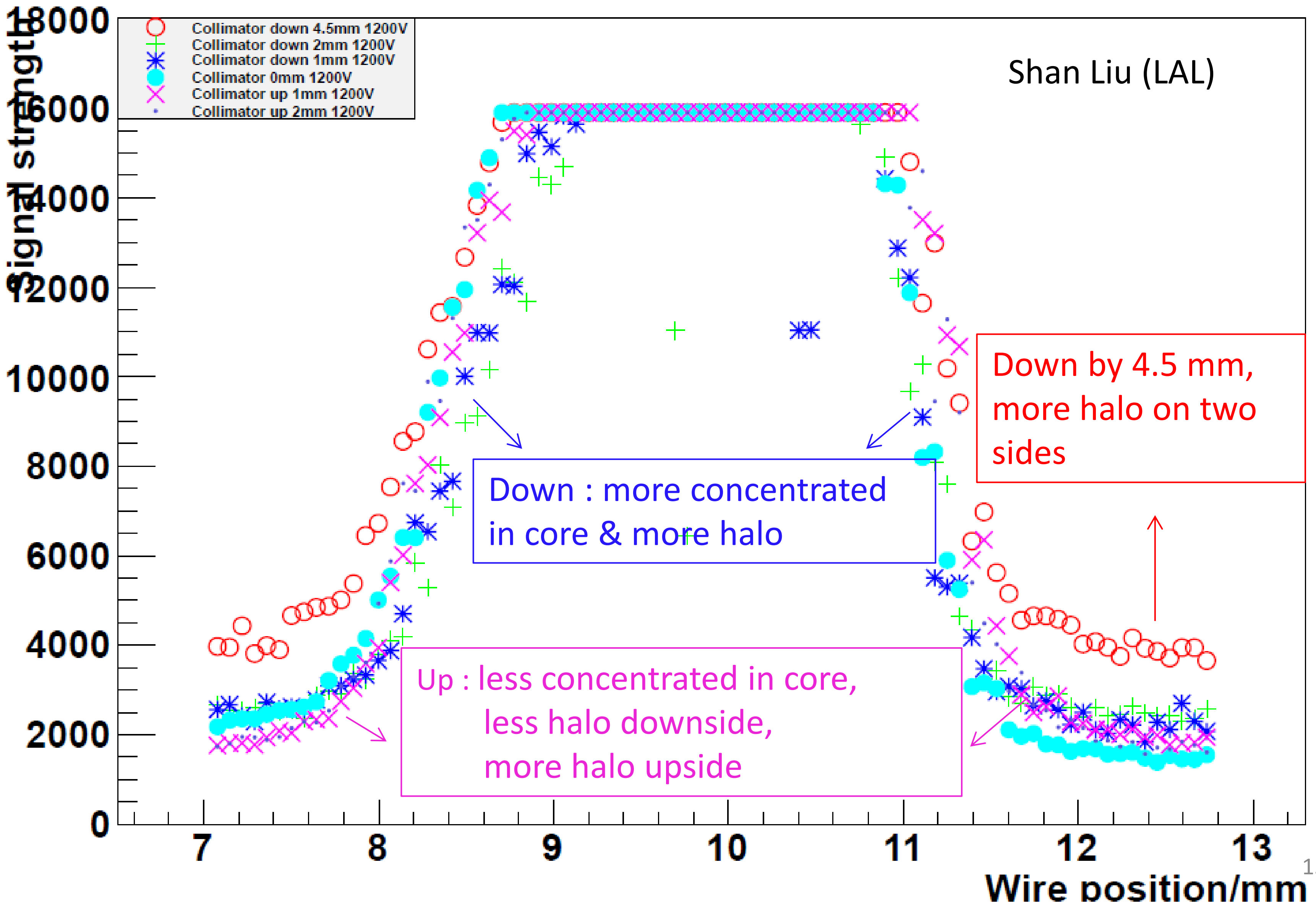
Phase difference between tapered beam pipe and Post-IP wire scanner :

$$\Delta\mu_y = 3\pi$$



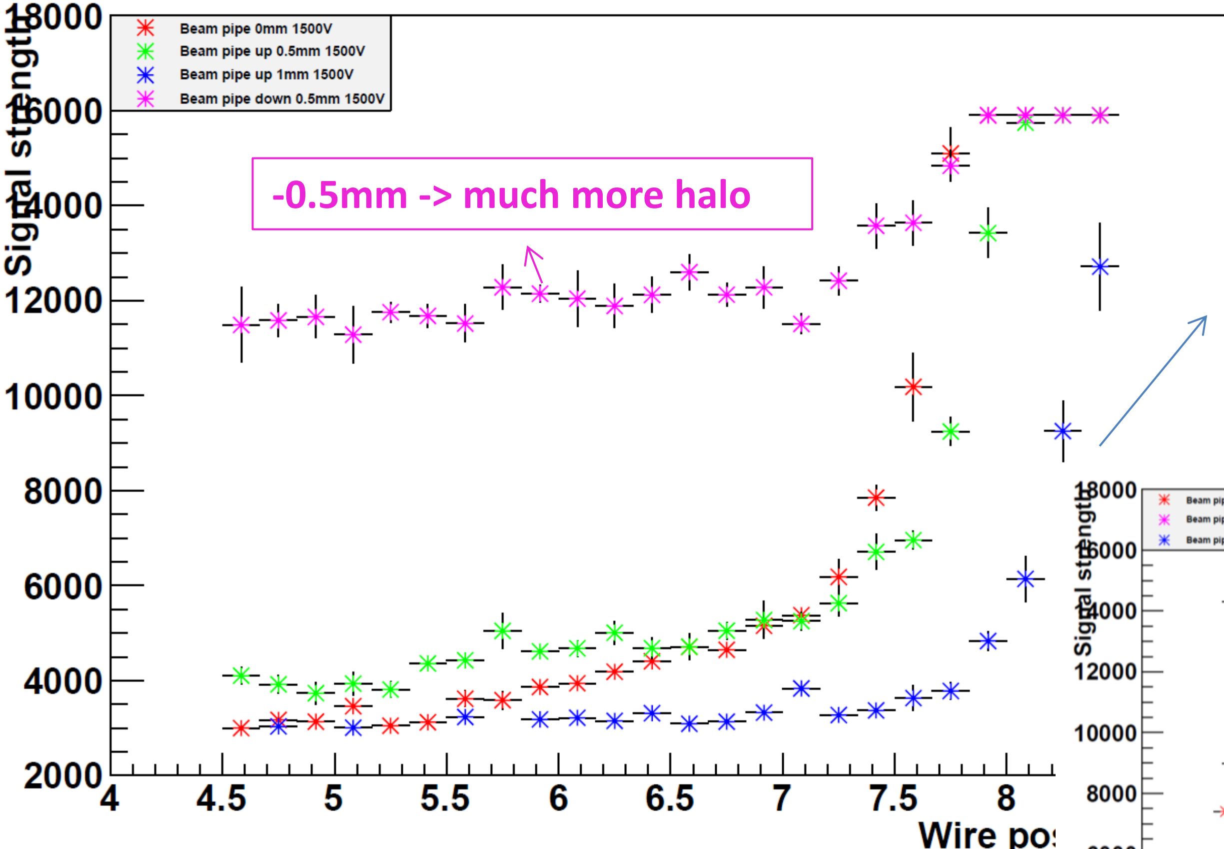
IP
halo
beam
tapered beam pipe
("collimator')
Cut on downside
"collimator" at 0mm
(beam is not centered)
"collimator" up
Cut less on downside,
edge moves down
"collimator" down
More Halo on two sides

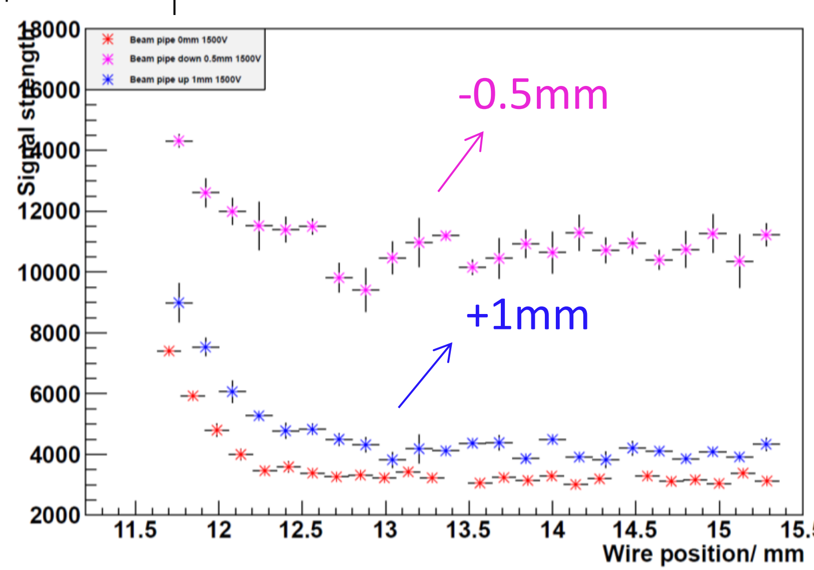
Effect of “Collimator” Movement on Beam Core



Effect of "Collimator" Movement on Beam Halo

Shan Liu (LAL)



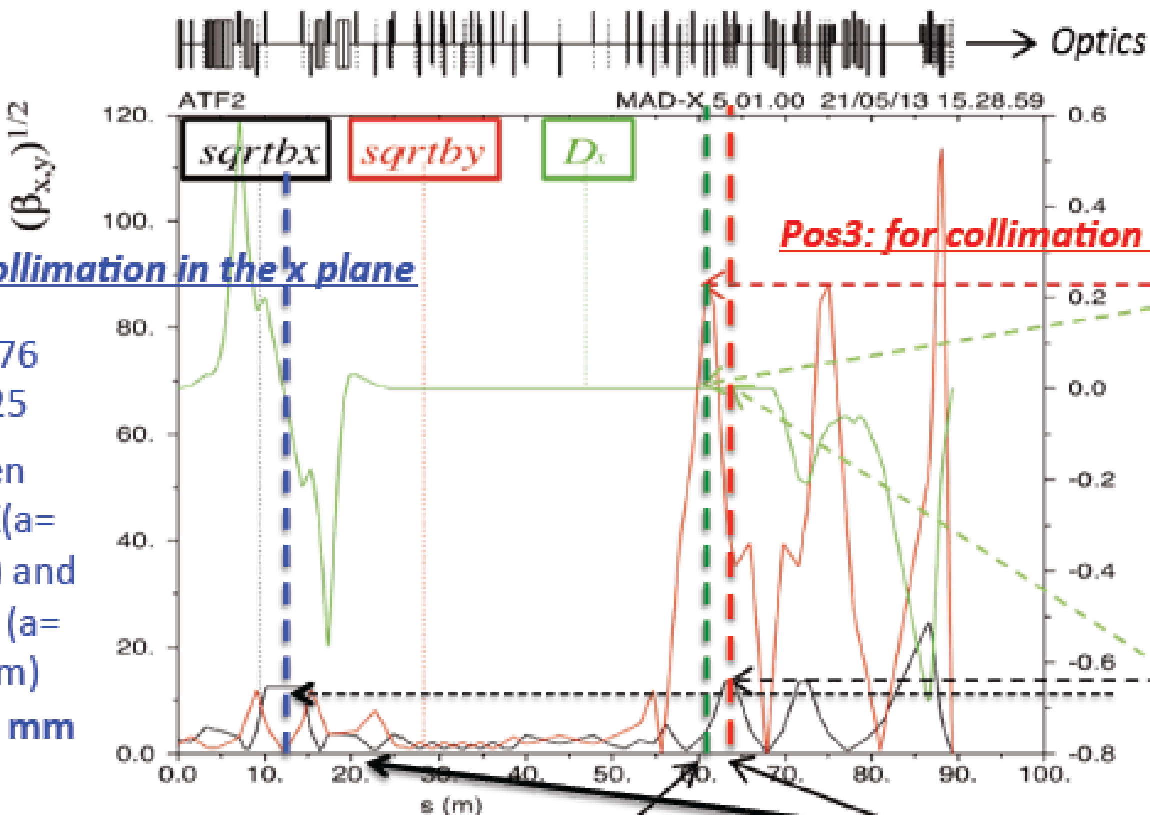


Move the beam pipe down leads to
more halo on both sides !

Betatron halo collimation: Scan of possible locations

- Two possible locations for a possible betatron horizontal collimator and one location for a possible betatron vertical collimator with high beta function and no dispersion

Nuria Fuster Martinez (IFIC)



Pos1: for collimation in the x plane

β_x =156.376
β_y =16.325

Between **MQD3FX**(a=(20.5)mm) and **MQD4FX** (a=(20.5)mm)

L_{drift}≈2000 mm

Pos3: for collimation in the x plane

High β_y and no dispersion

β_x =179.637
β_y =1572.127

Between **MMQF9BFF** (a=(10)mm) and **MMSF6FF** (a=(10)mm)

L_{drift}≈400 mm

High β_x and no dispersion

*Position to put the **vertical betatron collimator***

*Position to put the **horizontal betatron collimator***

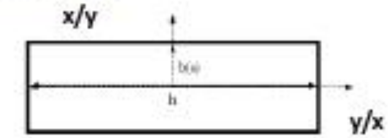
Pos2: for collimation in the y plane

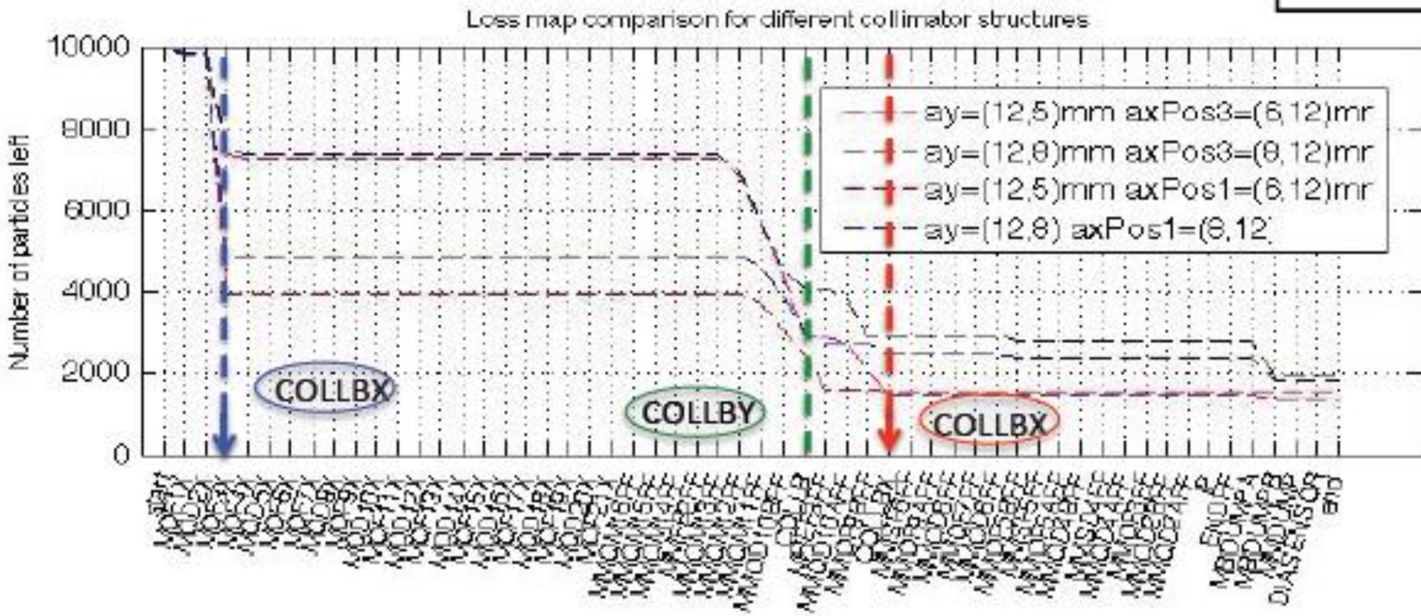
β_x =35.622
β_y =9034.032

Between **MMQD10BFF**(a=(10) mm) and **MREFF3FF** (a=(-))

L_{drift}≈700 mm

Results: Loss map comparison for **Pos1** and **Pos3** trfor a rectangular and horizontal halo collimator





	MQF4X	COLLB	IP	MBDUMPA	DIASENSOR
ay=(12,5)mm ax=(6,12)mm	26.9900	70.9600	85.6200	85.6200	86.3400
ay=(12,8)mm ax=(8,12)mm	26.1700	58.8300	72.0600	72.0600	80.4900
ay=(12,5)mm ax2=(6,12)mm	60.4100	75.5900	84.6700	84.6700	84.6700
ay=(12,8) ax2=(8,12)	51.0100	69.6000	75.9900	75.9900	81.7200

- With the collimator at **Pos1** we avoid losses at the FD with an aperture of 5 mm in the direction of collimation while if we put the collimator at Pos3 we still have losses at the FD
- The drift space at **Pos1** is bigger
- **Pos1** is farther than **Pos3** from the IP

Nuria Fuster Martinez (IFIC)

Diamond Detector Features

Property	Diamond	Silicon
Density (g m^{-3})	3.5	2.32
Band gap (eV)	5.5	1.1
Resistivity (Ω cm)	$>10^{12}$	10^5
Breakdown voltage (V cm^{-1})	10^7	10^3
Electron mobility (cm^2 V^{-1} s^{-1})	1700	1500
Hole mobility (cm^2 V^{-1} s^{-1})	2100	500
Saturation velocity (μm ns^{-1})	141 (e$^-$) 96 (hole)	100
Dielectric constant	5.6	11.7
Neutron transmutation cross-section(mb)	3.2	80
Energy per e-h pair (eV)	13	3.6
Atomic number	6	14
Av.min.ionizing signal per 100 μm (e)	3600	8000

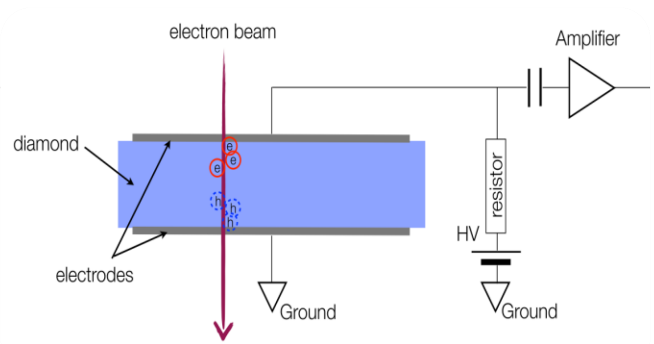
ADVANTAGES

- *Large band-gap⇒low leakage current*
- *High breakdown field*
- *High mobility⇒fast charge collection*
- *Large thermal conductivity*
- *High binding energy⇒Radiation hardness*
- *Fast pulse ⇒several ns*

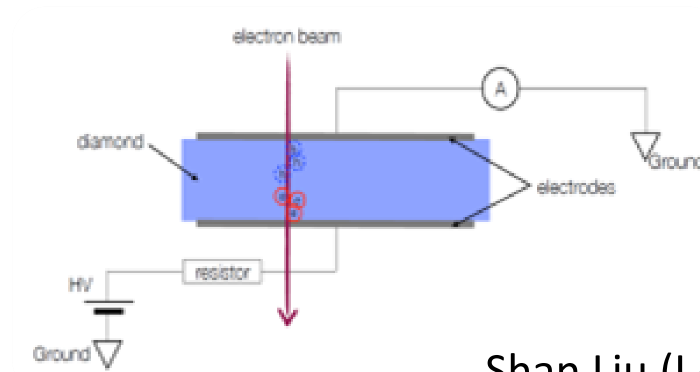
Need very large dynamic range

	Total #	Max. #/mm^2 @ Sensor	Charge signal/mm^2
Beam	10^{10}	$6.16*10^7$	1.6887μC
Halo	10^7	$2.24*10^4$	61.376pC
Compton	28340	$5.2*10^2$	1.4284pC

High voltage side readout



Low voltage side readout



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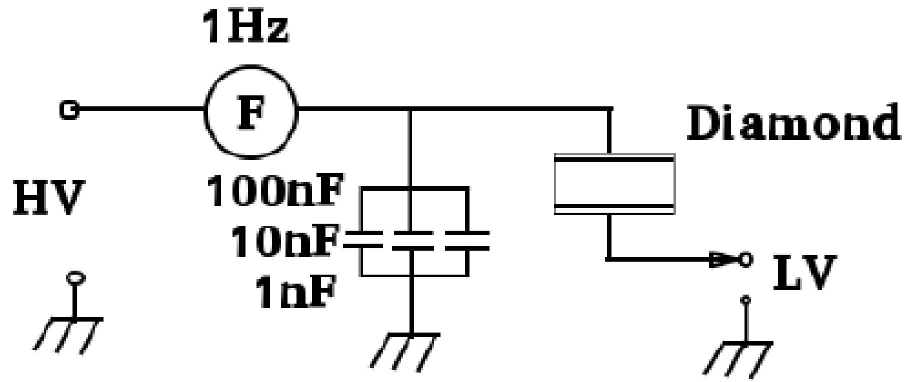
New Diamond

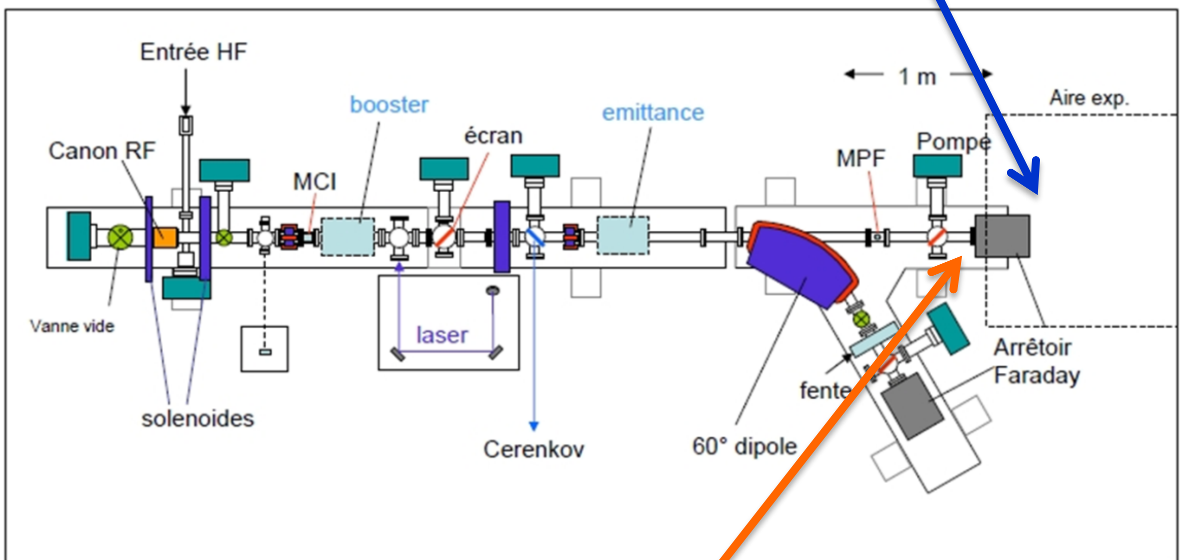


- Single-Crystal Diamond Detector
- Substrate size: 4.5mm * 4.5mm * 0.5 mm
- Charge yield: 3fc/MIP[1]

[1] http://www.cividec.at/.

Diamond Detector Test @ PHIL

Test of fast remote readout (fast heliax coax cable + high BW scope) with particles at end of beam line, using existing single crystal 4.5x4.5mm CVD diamond pad sensor



In-vacuum single crystal CVD diamond sensor profile scanner -> for PHIL and ATF2 diagnostic

("plug compatible" design)

PHIL Electron Beam Parameters

(given by ***Hugues Monard***)

- ✓**Charge: up to 400 pC /bunch (1 bunch per RF pulse) ;**
- ✓**Duration of Charge: 7 ps FWHM;**
- ✓**Charge Stablility: < 2%;**
- ✓**Maximum Energy: 5 MeV;**
- ✓**Minimum Dispersion: < 1%;**
- ✓**Beam Size -> few mm after exit**

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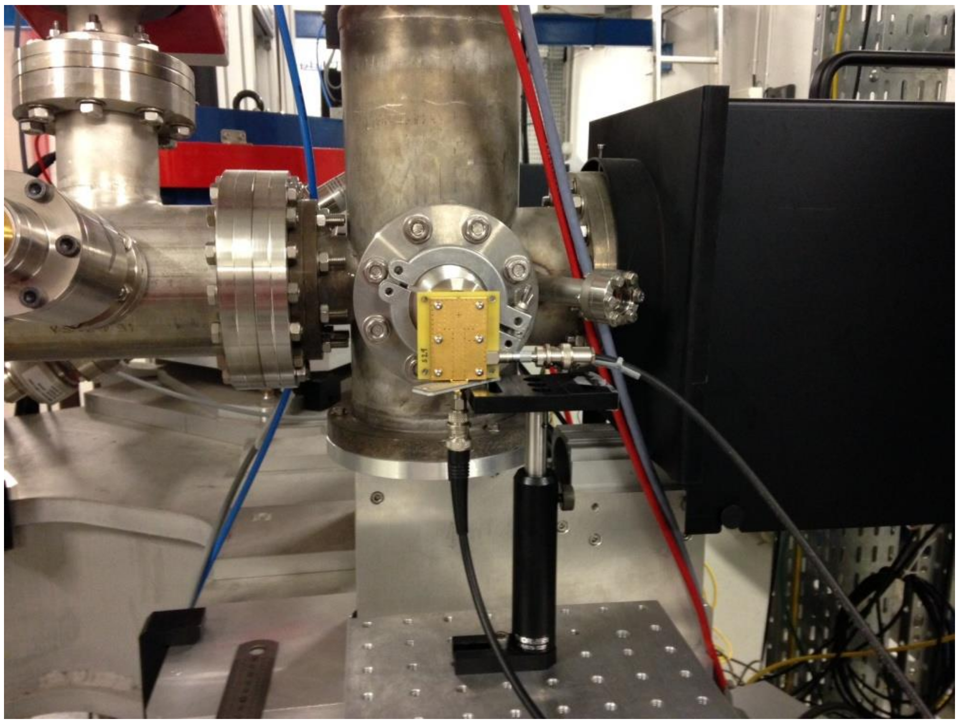
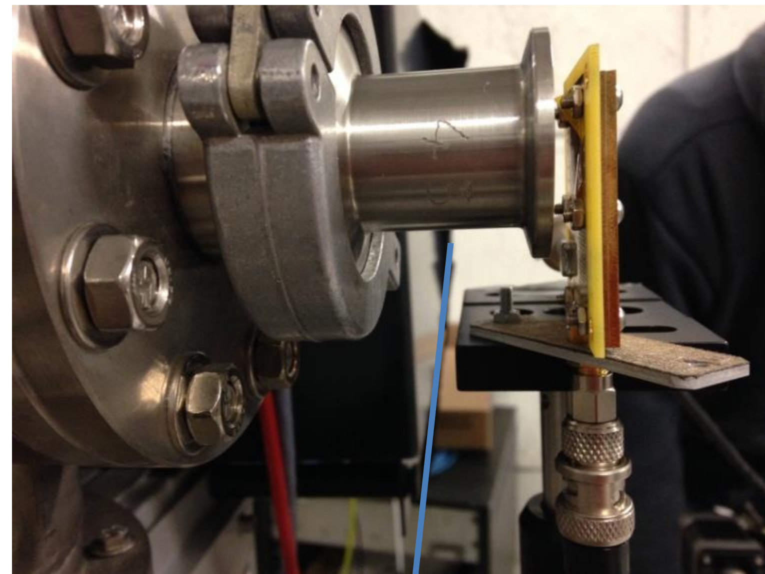
Test without external shielding box





R=2mm collimator

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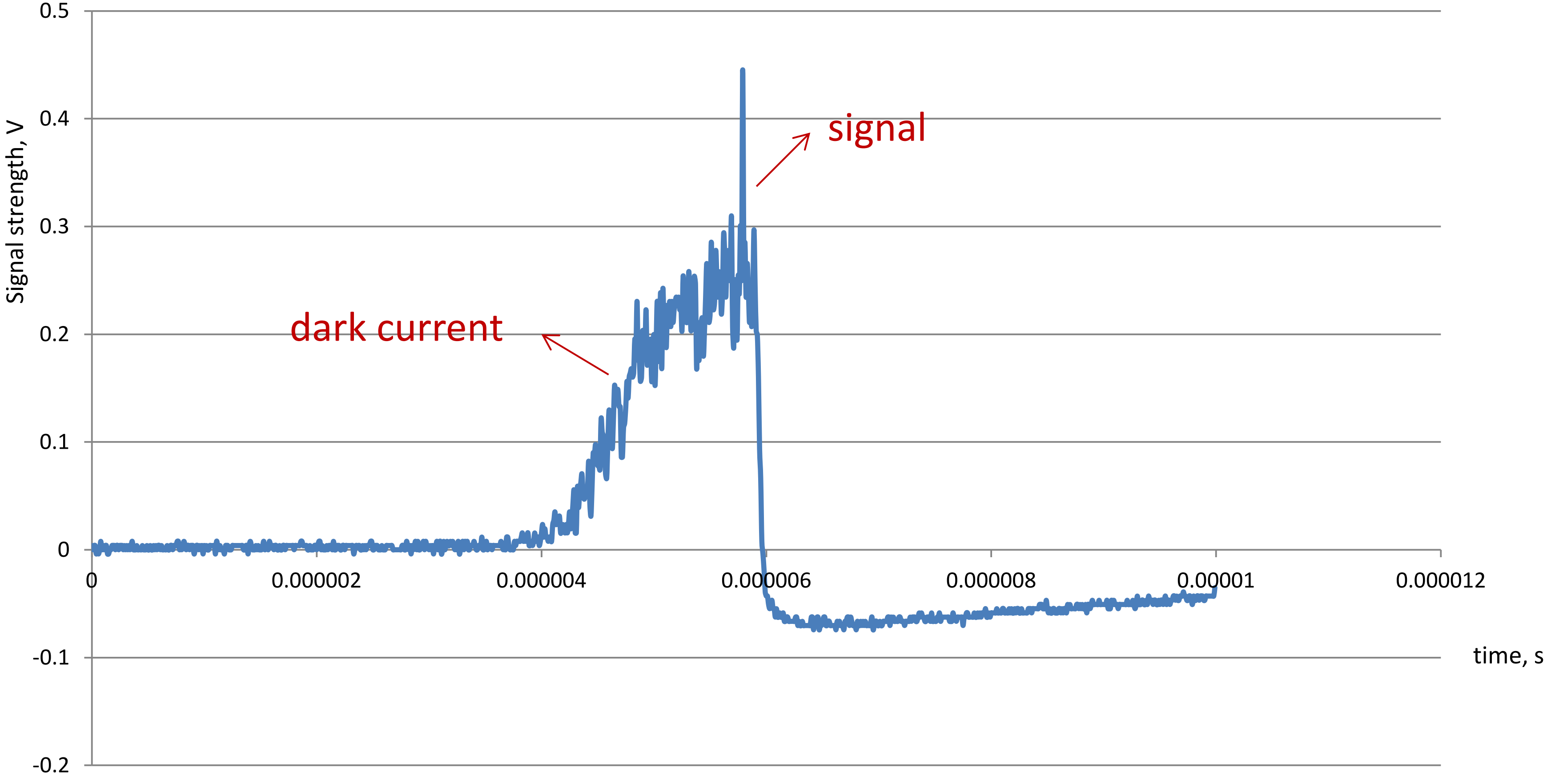
Signal on top of dark current



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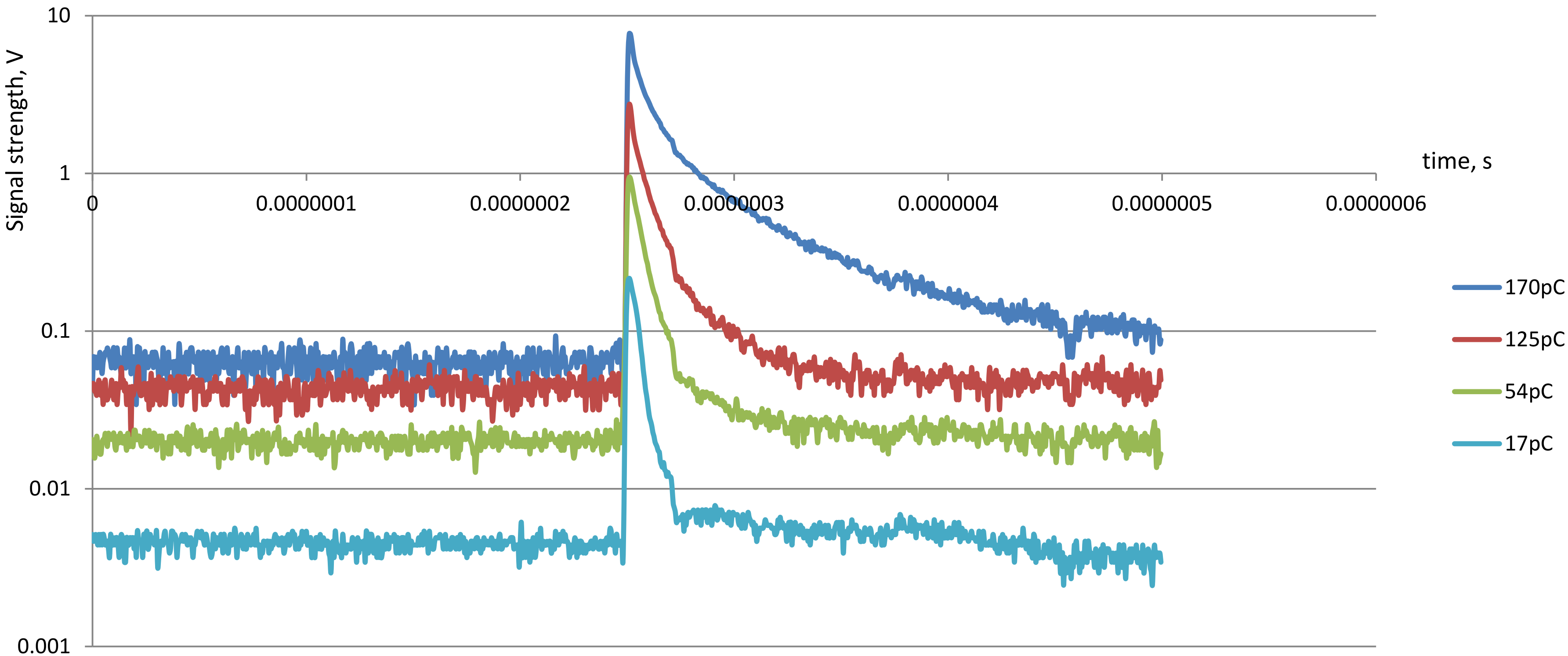
Signal pulse develops tail for increasing beam charge



16 pC → 10^8 electrons (~ 10 times less on diamond with 2mm collimator)

100 m ¼ heliax coax + 24 dB attenuator before scope

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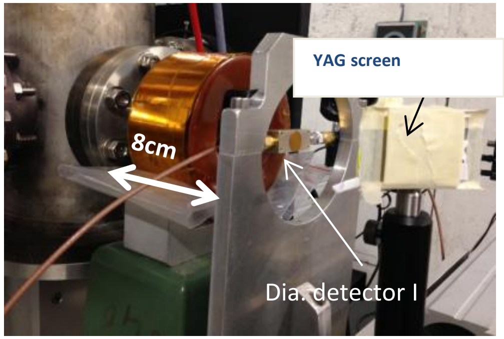
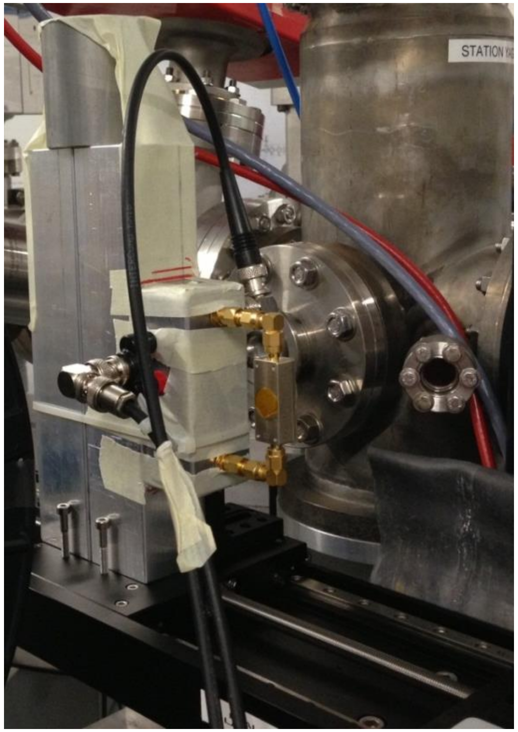
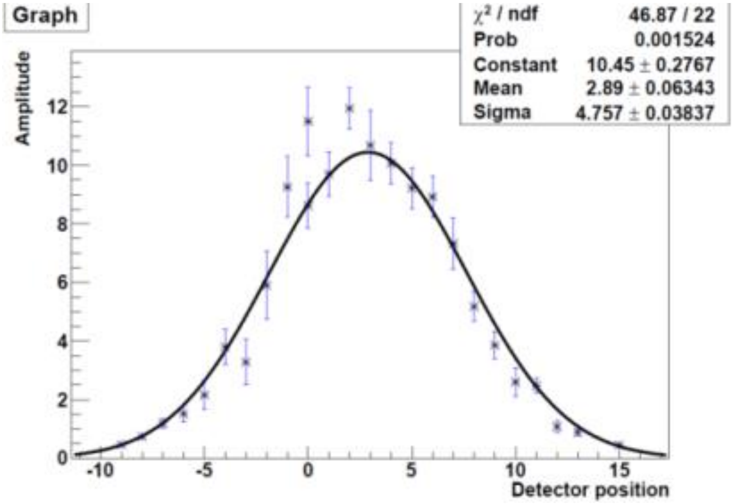
Beam size measurement with older diamond sensor







Beam size mesurement using Diamond detector:

YAG screen measured beam size : 4.45 mm ; Diamond size : 4.5X4.5 mm

$\sigma_x^{2} = \sigma_m^{2} - (4.5/\sqrt{12})^2$, σ_m=4.757 mm -> detector measured beam size σ_x=4.57 mm

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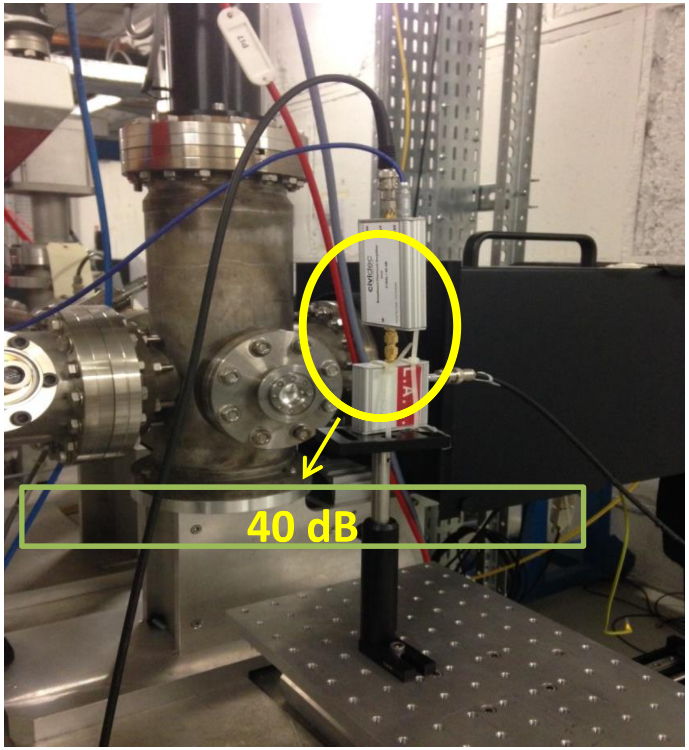
CIVIDEC Amplifier

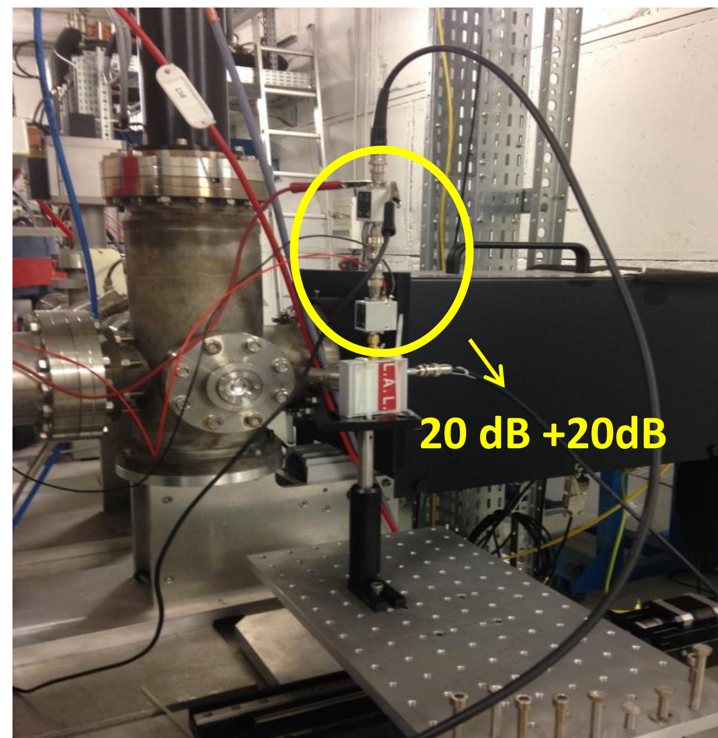


Parameters:

Type:	Current amplifier
Analog bandwidth:	1 MHz – 2 GHz
Gain:	40 dB
Radiation hardness:	1 MGy
Input coupling:	AC coupled with 1.5 nF
Input impedance:	50 Ω
Input protection:	IEC61000-4-2 (±8 kV, 2 A for 1 µs)
Input polarity:	Bipolar
Output polarity:	Non-inverting, bipolar
Linear output voltage range:	±1 V
Output impedance:	50 Ω
RMS noise:	2.5 mV (3.5 dB)

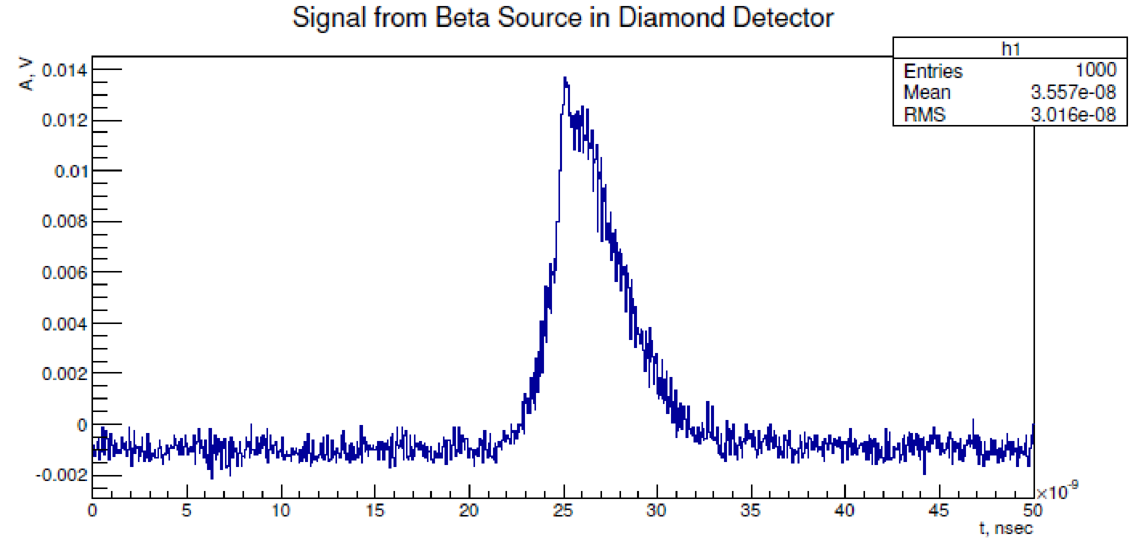
Frequency Min.	0.01	(MHz)
Frequency Max.	1000	(MHz)
Gain Minimum	20	(dB)
Gain Flatness	0.75	(dB+/-)
Noise Figure	3.4	(dB)
Input VSWR	2:1	(Ratio)
Output VSWR	2:1	(Ratio)
Output P1dB	14	(dBm)
Voltage 1 Nom.	15	(V)
Current 1 Typ.	60	(mA)
Impedance	50	(Ohms)

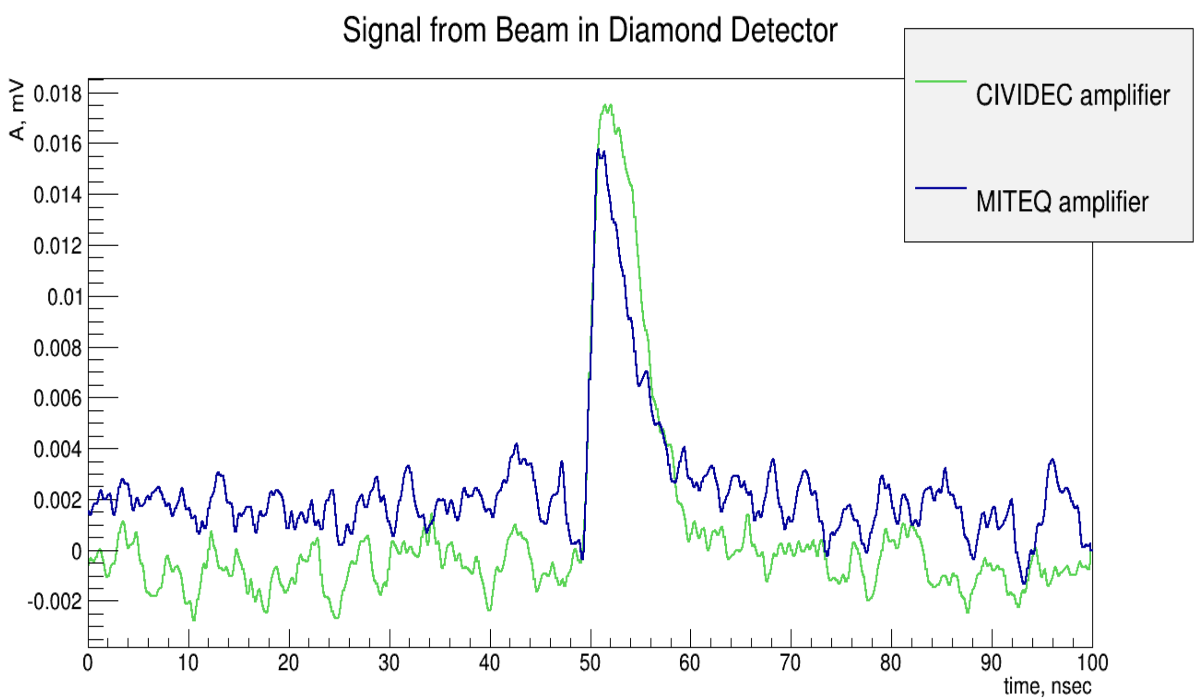
MITEQ Amplifier



~ 1 MIP from ^{90}Sr β source

- Energy decay for Sr-Y90: 0.546 MeV and 2.28 MeV



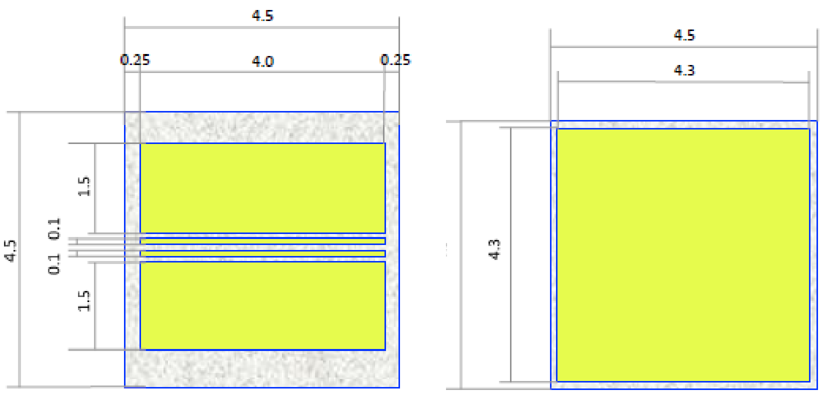


Single electrons detection at PHIL ?

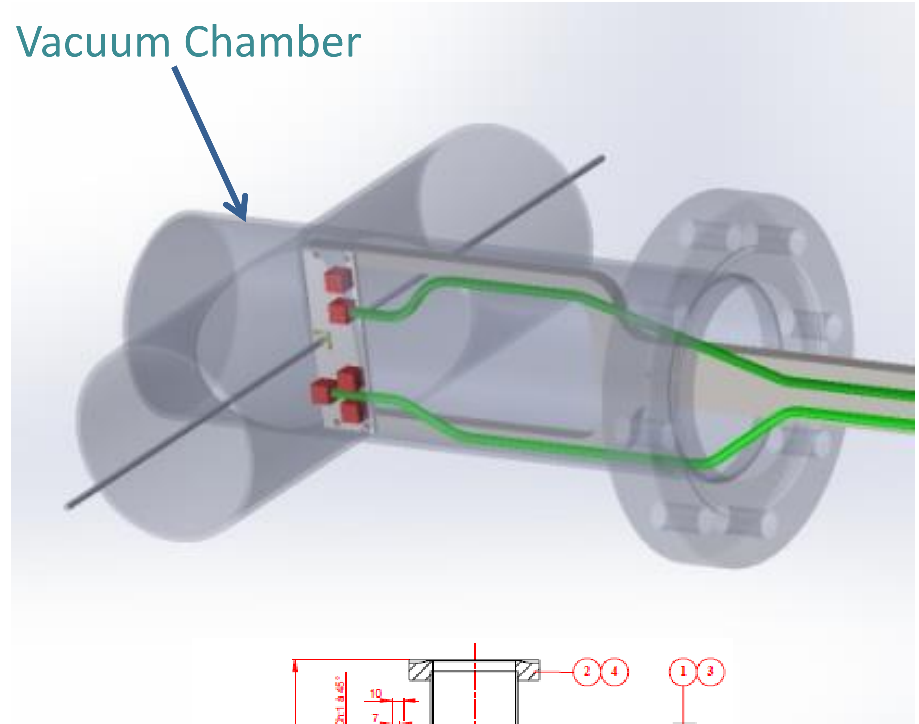
(sensor displaced 7cm from beam axis)

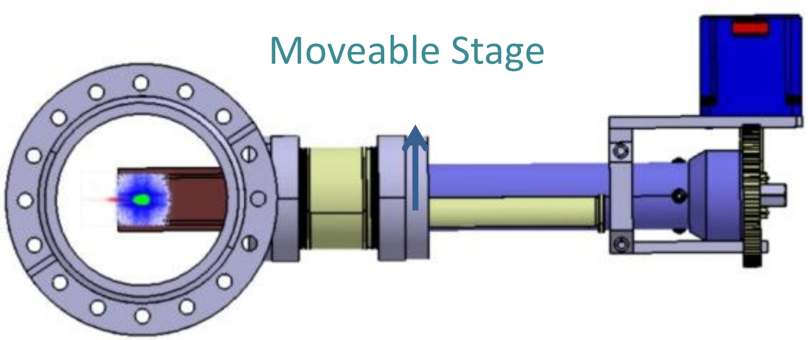
Shan Liu, Illia Khvastunov (LAL)

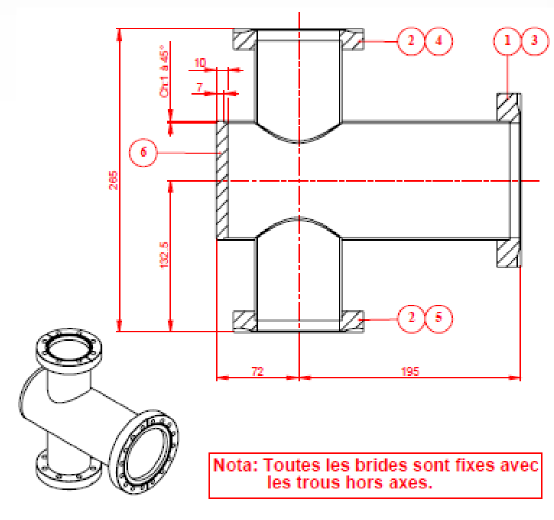
“Plug-compatible” design for ATF2 & PHIL



TOP SIDE BOTTOM SIDE







Frédéric Bogard (LAL)

Issues & Prospects

- ✓ **Several tests of diamond detector done in air at PHIL → more tests are planned to finalize details of the electronics**
- ✓ **Observe long tail for large signals from PHIL beam → due to electronics or other physics effects ? Issue of linearity…**
- ✓ **Using amplifier or attenuator with 1-2 GHz bandwidth, CIVIDEC diamond sensor measures signal from 1 to 10^8 electrons → S/N ratio of these measurements needs to be studied**
- ✓ **Two sets (diamond sensor + mechanics) will be ordered & prepared for application in vacuum → one for PHIL, another for ATF2. Plan test at PHIL early 2014 and install at ATF2 in June/July**
- ✓ **Proposal for horizontal & vertical moveable halo collimators being prepared with IFIC group**
- ✓ **Simulation (BDSIM, CMAD) and analytical work for halo modeling**