


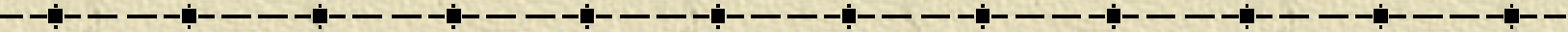
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- 1) *A SMALL SURVEY ON
BEAM DIAGNOSTICS FOR
SMALL SIZE BEAM*
 - 2) *SHORT PRESENTATION ON
ACCELERATOR R&D AT LAL
(ORSAY)*

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Abstract

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- ✦ The problem of measuring and controlling small beam sizes (much less than the mm) in linacs and transfer lines is particularly crucial for the main linacs of a linear collider, where the 6-D emittance has to be strongly reduced. The problem becomes more complicated when the beam intensity considered is very large. Some **invasive** and **non-invasive** diagnostics, which could be of interest for such application, will be presented and compared between them.
 - ✦ Since many years, the Accelerator group in LAL-Orsay is being involved in the study and realization of small and medium energy linacs. Some recent illustrations of this activity, related to electron injectors or to some linac components will be presented.

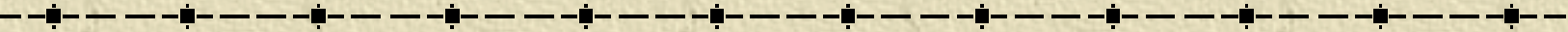
DIAGNOSTICS FOR SMALL SIZE BEAMS



✦ Introduction

- ✦ In order to assess the good behaviour of a beam in an accelerator, the knowledge of the 6-D emittance is necessary. This knowledge can be acquired during dedicated measurements or checked during control operation => *invasive/non-invasive*
- ✦ For the particular case of a linear collider, we need small sizes at IP, in order to increase L . Thus, beam emittance is damped in PDR and DR.
- ✦ Moreover, high intensities are required. The conjugation of small sizes with large intensities with, hence, a high density of particles, makes:
 - the sensitivity, easier
 - the resolution and the problem of damages (invasive), harder for beam profile monitors

SOME BEAM PROFILE MONITORS FOR SMALL SIZE BEAMS



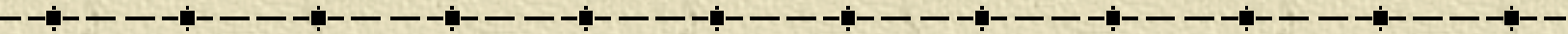
✦ The following tools will be considered:

- wire scanners
- gas ionization detectors
- laser wires
- laser interferometer
- optical radiation detectors:

Optical Transition Radiation

Optical Diffraction Radiation

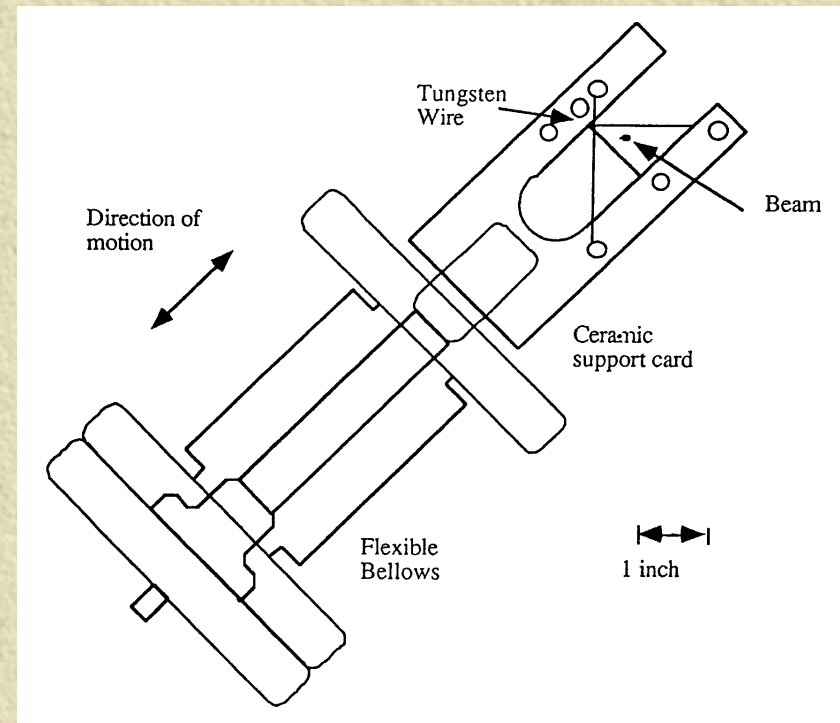
WIRE SCANNER



- ✦ Device with a thin fiber (tungsten or carbon) moving across the transverse section of the beam.
- ✦ Interception of the beam produces bremsstrahlung photons and secondary emission electrons. Either γ rays or secondary e^- can be used for the information on beam profiles (H & V).
- ✦ The W.S. is attached to a precision stepped device moving with μm steps.
- ✦ The rms resolution of a W.S. is $d/4$, where d , is the wire diameter. A $5 \mu\text{m}$ rms beam measurement would be widened by only 6% , with a $7 \mu\text{m}$ diameter W.S.

Some details on Wire Scanners

- ✦ Usually, two wires (H&V) are mounted on a fork which is displaced at 45 degrees to the horizontal plane.
- ✦ In some cases, the γ rays are converted into pairs which create Cherenkov Radiation in a medium (ex. SLAC/FFTB).
- ✦ Minimum diameter size actually realized is of $4\ \mu\text{m}$, leading to a minimum resolution of $1\ \mu\text{m}$.

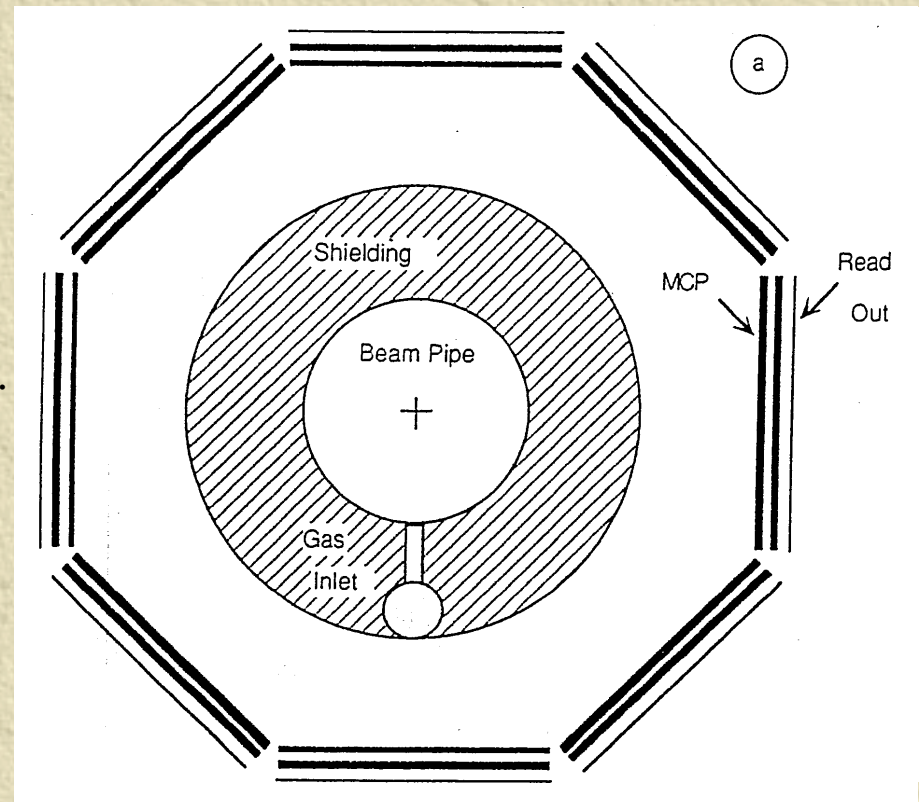


GAS-IONIZATION BEAM SIZE DETECTOR

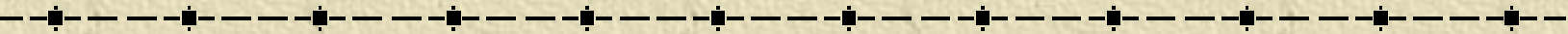
- ✦ *PRINCIPLE : the information on the transverse dimensions is obtained through the kick given to the ions by the passage of the electron bunch. At high energy, the space charge field of the bunch is mainly transverse. The image of a “cloud” of quasi-real photons can be used. (W-W method).*
- ✦ *The ions are produced by the electrons of the bunch in a gas. Helium as Argon are used.*
- ✦ *If we consider Ar, for instance, the ions move only slightly during the passage of the beam and their maximum velocity is proportional to the maximum electric field; which is inversely proportional to the largest beam dimension (horizontal, for flat beams) The measurement of the **time of flight** of the ions to the detector provides the horizontal dimension*
- ✦ *Measurement of the angular distribution provides bunch aspect ratio*

Some informations on gas-ionization detector

- ✦ The ion detector consists of **microchannel plates** put around the beam tube at some cm distance of the beam axis. Before reaching the MCP's, the ions pass through a narrow slit (W); potential difference slit-MCP [2-3 kV] allows final acceleration of the ions.
- ✦ Gas is injected by a small inlet in the tube
- ✦ Vertical sizes as small as 60 nm have been measured at FFTB (Orsay team)
- ✦ Considered at CERN for LHC



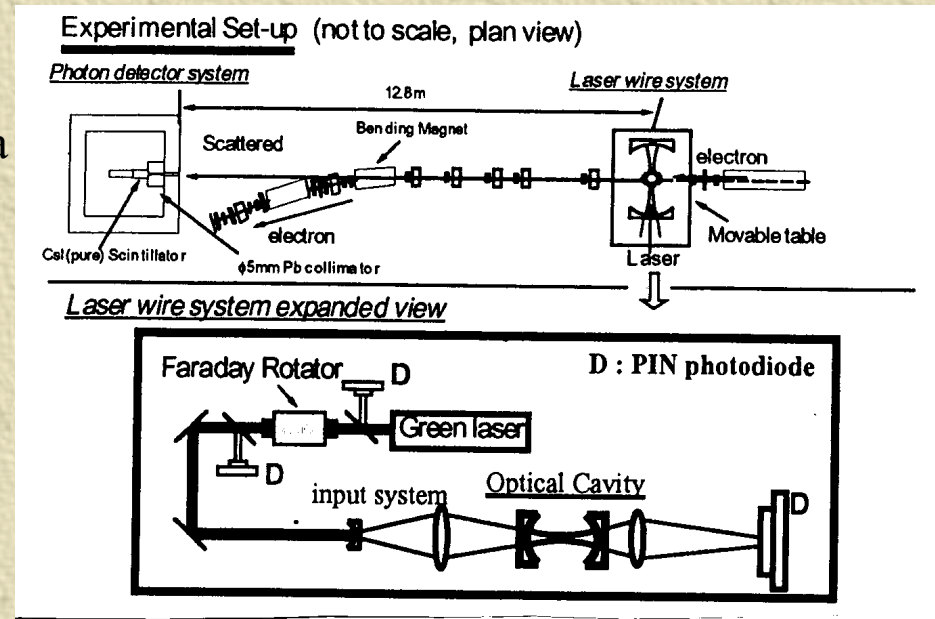
LASER WIRE MONITOR



- ✦ Principle : Compton scattering of the electron beam by a laser light sent at right angle to the beam. The emitted (hard) photons are measured in the forward direction.
- ✦ The laser beam waist is realized in the center of a Fabry-Perot cavity
- ✦ The counting rates of scattered photons are measured as a function of the laser wire position
- ✦ The actual electron beam profile is obtained after deconvolution with the known laser distribution

Laser Wire Monitor: technical details

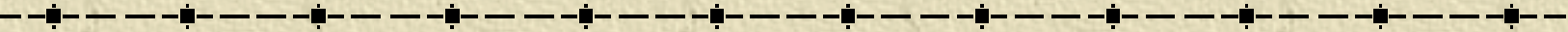
- ✦ Scattered γ are detected in the forward direction after having swept off the electrons.
- ✦ To detect the γ 's (some MeV, for a GeV e- beam and a visible laser light), use of scintillators [CsI, NaI,..]. Photomultipliers are associated with the scintillators.
- ✦ Scan with the laser beam can be realized, moving the optical table (method at ATF)
- ✦ A 10 μm e- beam has been measured at ATF; $\sigma=1 \mu\text{m}/\text{SLC}$
- ✦ Figure: typical scheme (ATF)
- ✦ Limits: $\sim \lambda$,wavelength:diffraction



Laser Interferometer Technique

- ✦ This technique, used by T. Shintake at FFTB, uses interferometry technique with a YAG-laser beam split into two beams which collide, perpendicularly, with an electron beam. The Compton back scattered γ , in the forward direction (e-) are directed to a γ -detector (Conv. + gas Cerenkov). As the laser light is stored in a cavity (SW), the γ 's present periodic variations with λ_{laser} along laser axis, when scanning the beam. Modulation depth \Rightarrow size
- ✦ This technique allows high accuracy; a 60 nm spot (V) was measured at FFTB.

OPTICAL RADIATION DETECTORS



- ✦ Optical radiation detectors can use Cherenkov radiation, Transition radiation, Diffraction radiation and of course, fluorescent screens. But due to the perturbation introduced by a physical medium (multiple scattering, energy deposition,.) we shall concentrate on two particular radiations: Transition radiation (with a very thin foil) and Diffraction radiation.
- ✦ Before describing these two possibilities, we shall get familiar with a useful method to describe them: the virtual or pseudo photon method (Weiszacker-Williams)

The Virtual Photon Method (Fermi, Weiszacker-Williams)

- ✦ The electric field created by a particle of charge Ze :

$$(e r_o / 4\pi\epsilon_o r_o^3) \cdot (1 - u^2/c^2)$$

$$E = \frac{\dots}{\dots}$$

$$[1 - (u^2/c^2) \cdot \sin^2\eta]^{3/2}$$

depends on the angle η between the direction of motion and the radius vector r_o . At high u ($\sim c$), the transverse component is much stronger than the longitudinal one. We have a **pancake** field shape. It is like a **plane wave**. \Rightarrow **photon cloud**

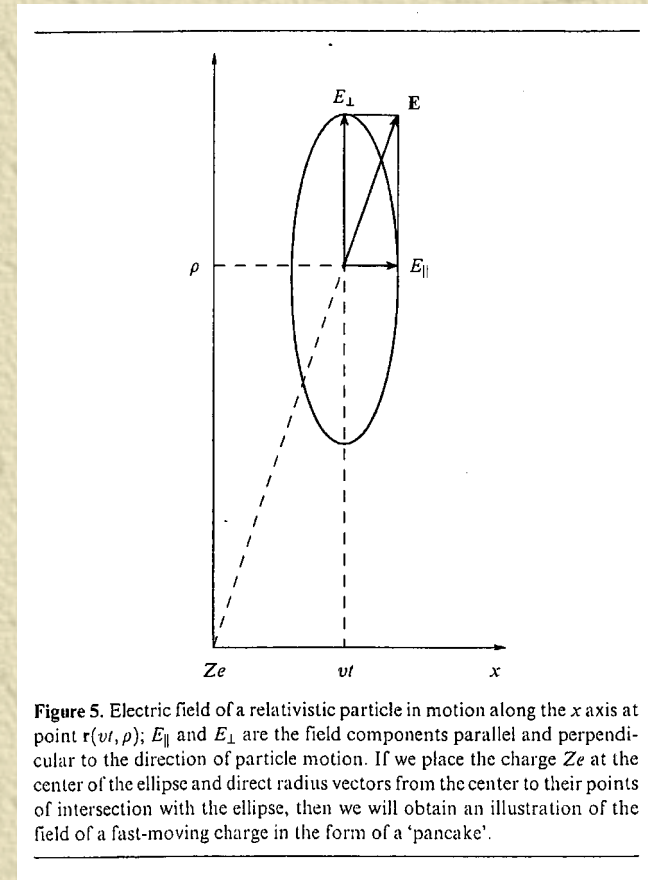
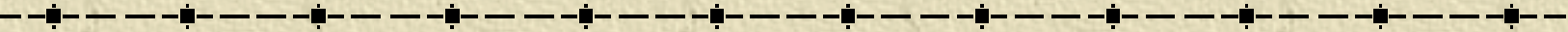


Figure 5. Electric field of a relativistic particle in motion along the x axis at point $r(vt, \rho)$; E_{\parallel} and E_{\perp} are the field components parallel and perpendicular to the direction of particle motion. If we place the charge Ze at the center of the ellipse and direct radius vectors from the center to their points of intersection with the ellipse, then we will obtain an illustration of the field of a fast-moving charge in the form of a 'pancake'.

Virtual Photon Method



✦ The photon cloud has a transverse dimension: $\gamma \cdot \lambda / 2\pi$

- ✦ When the electron beam propagating in vacuum with the associated Coulomb field in the form of the photon cloud meets:
- an inclined surface=> Transition radiation (backward and forward). The **backward radiation** → reflection of the photon cloud on the surface
 - a hole or an edge, smaller or closer to the axis than the photon cloud transverse dimension → diffraction=>**diffraction radiation**

TRANSITION RADIATION

✦ Transition radiation is created when a charged particle crosses the interface between two media of different optical properties.

- The radiation is emitted in two directions:
- -Forward: in direction of beam propagation
- -Backward: in direction of specular reflection.

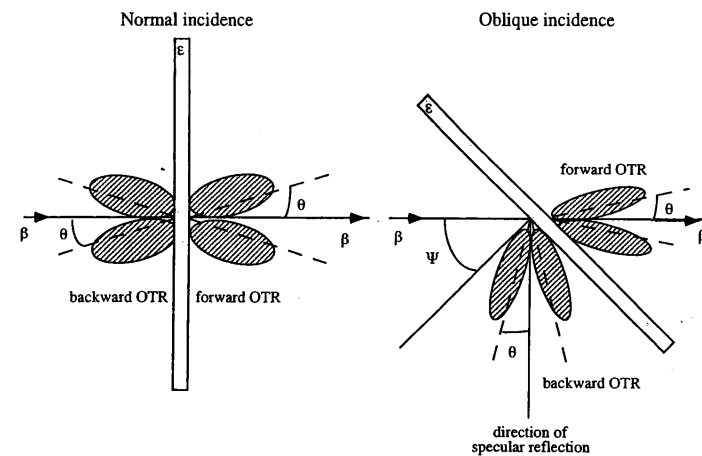


Figure 2.1: Transition radiation emitted into vacuum; normal and oblique incidence.

TRANSITION RADIATION : *possible measurements*

✦ Bunch length: due to the rapid formation of the radiation ($\sim 10^{-13}$ s), it is possible to measure very short bunches:

- * With a **Streak-Camera** (SC): the limitation is brought by the SC resolution (\sim ps)
- * With **coherent TR** using wavelengths comparable to the bunch size: resolution $<$ ps

Transverse phase space:

transverse dimensions are measured with CCD cameras at the image plane of the lens

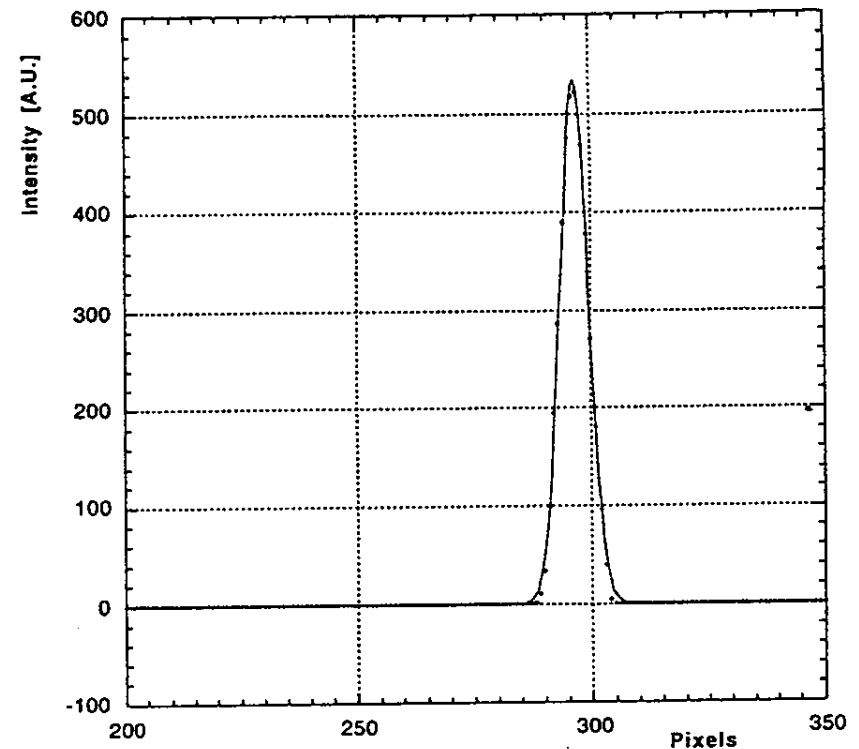
angular distributions are measured with a CCD camera at the focal plane of the lens.

Beam energy:

determined by the angular position of the maxima ($1/\gamma$). More precision is obtained with interferometer (Wartski)

Transition Radiation: some activities at LAL-Orsay

- ✦ The more “recent” activities with OTR in our laboratory, concerned:
 - * a test on the OTR resolution on the 2 GeV Orsay e- linac
On figure H profile,
 $\sigma=0.3$ mm
 - * a series of measurements on the Tesla Test Facility (TTF) at DESY. In that case, beam emittance has been determined and observations on beam behaviour inside the pulse, also.
- > PhD report of A.Variola



Measurement of transverse dimensions with OTR: the problem of resolution

✧ OTR angular distribution \rightarrow peaked into a cone of half aperture $1/\gamma$. Doubt about obtaining good geometrical resolution at high energy due to “self diffraction” of OTR spot. The *self diffraction*, expressed with Heisenberg relation:

✧
$$\Delta x \Delta p_x > h/2\pi$$

✧ Using the relations $p = h \cdot k/2\pi$ and $\Delta k_x = k \Delta \alpha_x$, we get in the case of separate measurements for angle and dimension:

$$\Delta x \Delta \alpha_x > \lambda/4\pi$$

Referring to such relation and taking as $\Delta \alpha_x$, $1/\gamma$, certain authors have *abusively* concluded that the spatial resolution will be worse than $\lambda\gamma$ (ex, 5 cm at 50 GeV for optical λ). But:

- Heisenberg relation concerns rms values (and rms $\gg 1/\gamma$)

- A large part of OTR intensity, emitted in angles $\gg 1/\gamma$

\Rightarrow Many works to determine theoretically and experimentally *OTR resolution*

Study of OTR resolution

✦ Theoretical & Experimental studies to determine resolution

✦ Theoretical: Rule&Fiorito, X.Artru et al, M.Castellano

PhD thesis (K.Honkavaara: Orsay)

{Figure from PhD report of KH}

- Experiments at LAL-Orsay (2 GeV), CEBAF (4 GeV) and CERN (22 GeV), showed an OTR resolution $\ll \lambda\gamma$
- \Rightarrow practical resolution: FWHM
- of the diffraction function
- \Rightarrow **OTR measurements of small beams at high energy: possible**

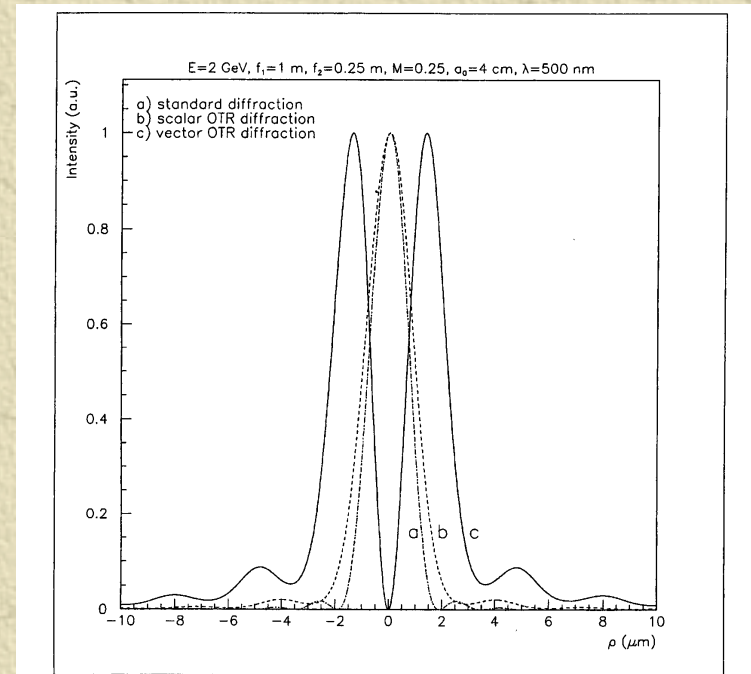


Figure 4.9: Standard diffraction pattern given by Eq. (4.26) (curve a), "vector" OTR diffraction pattern given by Eq. (4.22) (curve c) and "scalar" OTR diffraction pattern given by Eq. (4.28) (curve b) on the image plane of a telescope with magnification $M = 0.25$. The parameters used are the same as in Fig. 4.4.

Diffraction Radiation

✦ Small recall:

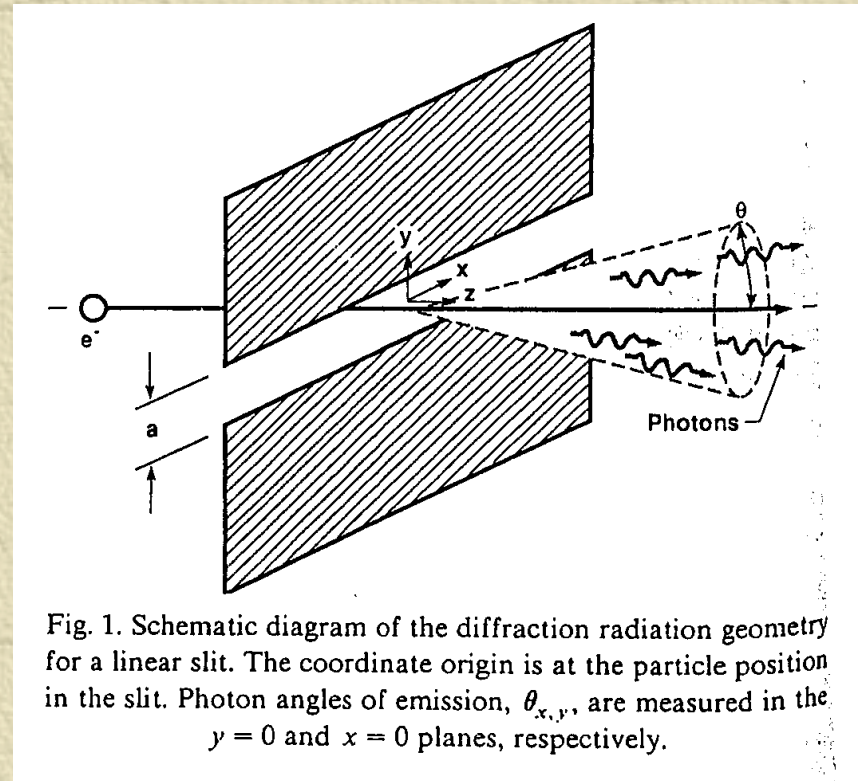
As for Cherenkov Radiation and Transition Radiation, the Diffraction Radiation was studied by Russian theoreticians Papers from 1958 (Y.Dnestrovskii and D.Kostomarov), analysed the radiation of a beam of particles passing through a circular aperture. Later, in 1962, A.Kazantsev and G.Surdovich studied the radiation of a particle beam, close to a metal screen. They considered this radiation as resulting from the **diffraction of the electromagnetic field of the particle by the metal screen.**

Diffraction Radiation: a simple approach

- ✦ We can consider the DR as resulting from the diffraction of the virtual photon flux by the aperture (hole, slit, edge).

[Figure from Moran in NIMB]

- ✦ The source of DR is a “disk” of diameter $\gamma\lambda/2\pi$. Consider a slit of aperture a :
 - * $\gamma\lambda \ll 2\pi a \Rightarrow$ DR radiation ~ 0
 - * $\gamma\lambda \gg 2\pi a \Rightarrow$ DR similar to TR
 - * $\gamma\lambda \sim 2\pi a \Rightarrow$ DR intensity $<$ TR, but enough for measurement



Diffraction Radiation: status

✦ Theoretical works worked out since a while (Ter-Mikaelian,..)

More recent calculations by Moran, Rule and Fiorito,
Castellano, Potylitsin, Artru

Measurements (few) are concerning :

- bunch length measurements (coherent DR; $\lambda \sim \text{mm}$); Y. Shibata et al
- transverse beam characteristics (slit 1mm, $\lambda = 1.6 \mu\text{m}$) at ELETTRA (team Castellano) and DESY (?)

At ATF, with an inclined edge at some tens of μm of beam axis. Detection of optical λ for 1.28 GeV e- beam (angular distrib.

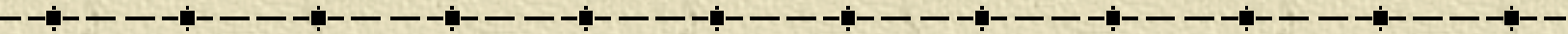
Nota: as for TR, the DR resolution depends on the optical acceptance

Due to its non-invasive character, DR will have large developments

Summary: comparison of different methods

		Ultimate	resolution	
Methods	Invasive ?	Limit (μm)	Defined by	Intense beam
OTR	yes	~ 10	CCD pixel size +optics	no
ODR	no	~ 10	CCD pixel size +optics	yes
Wire scanner	yes	~ 1	Wire diameter	no
Laser wire	no	~ 0.3	Laser (λ)	yes
Laser interferom.	no	~ 0.01	laser	yes
Gas ioniz.	no	~ 0.01	Long.space charge	yes

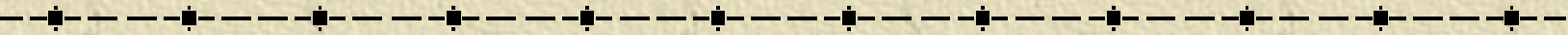
Some R&D on Accelerators at LAL-Orsay



✦ Some examples related to the R&D on Accelerators at LAL-Orsay, are presented. They concern:

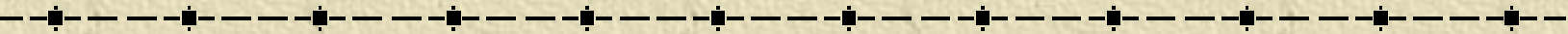
- * studies and realizations related to linear collider projects:
 - # injector for the drive beam of CTF3, for CLIC
 - # RF couplers for the TESLA cavities
- * study and realization of a small energy (<10 MeV) linac for research on rapid reactions in chemistry

Injector for CTF3/CLIC



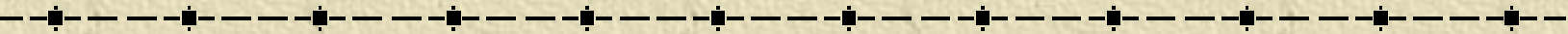
- ✦ For CLIC, the RF power is extracted from a drive beam of high intensity propagating in S-Band structures. The extracted power is feeding accelerator structures at 30 GHz.
- ✦ A facility (CTF3), using large part of the LIL installation, is to be built in order to validate the principle.
- ✦ LAL is being involved in the study and construction of:
 - * 1 gun CLIO-like at 90 kV, 2A max with 1 to 7 pulses of 20 ns and 1 A, separated by 450 ns (one ring revolution). Risetime < 1ns
 - * 1 gun SLAC-like at 140 kV, 7A; pulse width 1.6 μ s
 - * 2 pre-bunchers:
 - # 1 prebuncher 3 GHz with SW cell (60 kV, max)
 - # 1 prebuncher (inox) with very low Q

Injector for CTF3: status



- ✦ The CLIO-like gun has been delivered and works properly.
- ✦ The SLAC-like gun: to be constructed. The associated electronics are under development
- ✦ The prebunchers: to be constructed
- ✦ An agreement has just been signed, between CERN and IN2P3, for the provision of the new gun and of the prebunchers.

RF couplers for TESLA



✦ LAL is involved in the construction of RF couplers prototypes for TESLA. These prototypes are based on the current TTF linac design. But, they have a larger diameter: 80 mm. Because:

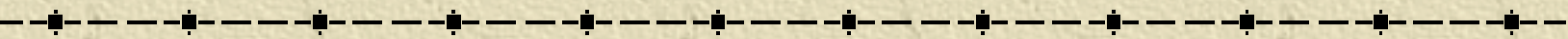
- they have to carry more power [2 MW instead of 250 kW]. Such design was conceived for the TESLA “superstructure” , alternative cavity design for TESLA {4x7cells cavities} with one coupler.

- the choice of the diameter is such to push the multipactor limits beyond the operating power. The coupler can also be DC biased to stop multipactor (cf LEP couplers)

Infrastructure to clean the coupler in ultra-pure water is in preparation.

The couplers will be “baked” in a 400 deg vacuum oven, before final assembly with the cavities in a “class 10” clean room. They will be tested with a 4.5 MW-1ms pulse Thomson Klystron

Short e- pulses for rapid reaction chemistry



- ✦ The project ELYSE consisting in a 9 MeV electron linac with an RF gun is destined to allow studies of rapid reactions in chemistry.
- ✦ Two synchronized pulses are used: the first initiates the reaction and the second interacts with the excited system. The informations derived from the system, associated to the delay between the two pulses, provide some knowledge on the reaction path during that time interval.
- ✦ A laser (Sapphire-Titanium) is triggering a Cs₂Te photocathode (QE~0.01) . The λ used is 266 nm.
- ✦ Two possibilities are then offered to the chemists:
 - use of photon pulses (photolysis)
 - use of electron pulses (radiolysis)

Comparison between the two modes is foreseen.