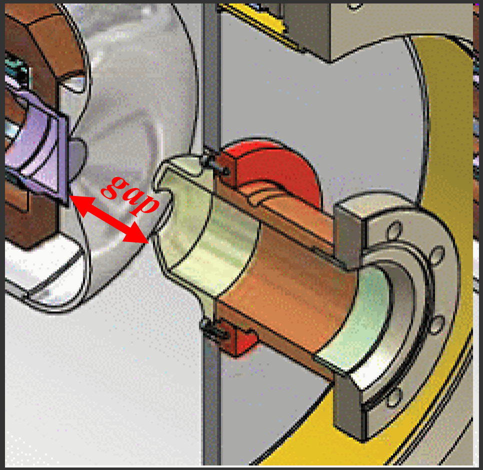
Electrode shaping in DC gun for low emittance beam

0) *It must work!*
1) *Cathode field*
2) *Gun voltage*
3) *Transverse focusing*
   a) *Electric*
   b) *Magnetic*
4) *Parametrized geometry*
5) *Other ideas…*

Cathode field

1) *Cathode field $E_{||}$ = V/gap, sets min spot size for a given bunch charge (and emittance)*

$$r \sim 2\sqrt{\frac{q/\pi}{\varepsilon_0 E_{||}}}$$



E.g. V = 500 kV, gap = 5cm
$\Rightarrow E_{||}$ = 10 MV/m, r = 1mm

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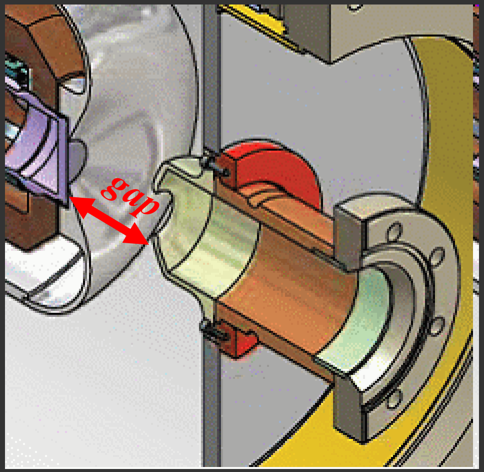
Gun voltage

2) *Space charge in the gun vicinity $F_{\perp} \propto 1/\gamma^2$*
e.g. 250kV is 56% worse than 500 kV
750kV is 56% better than 500 kV

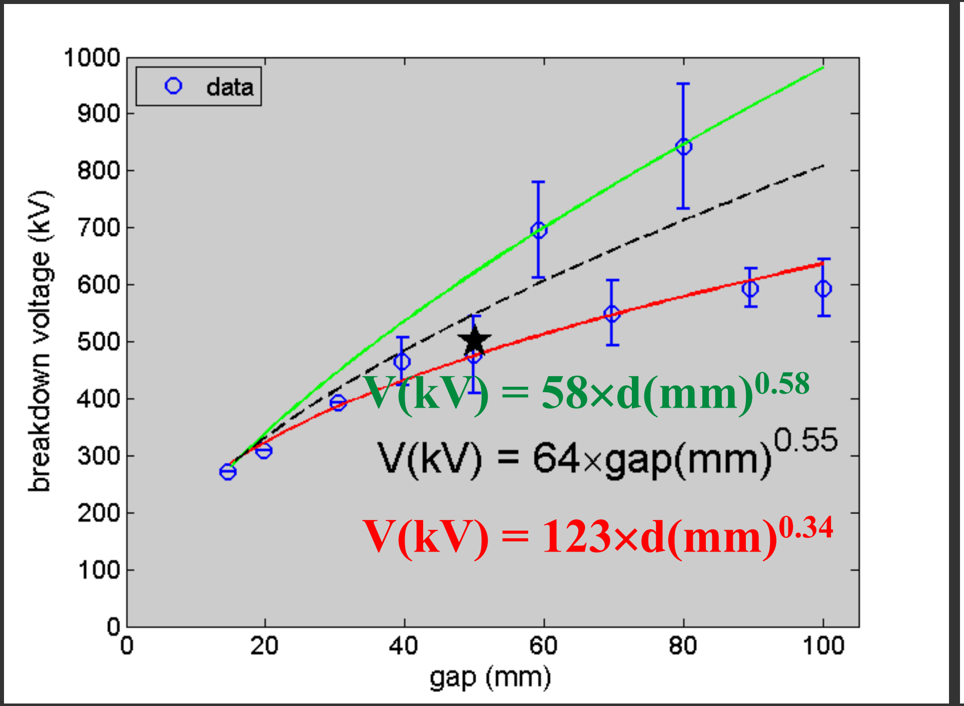


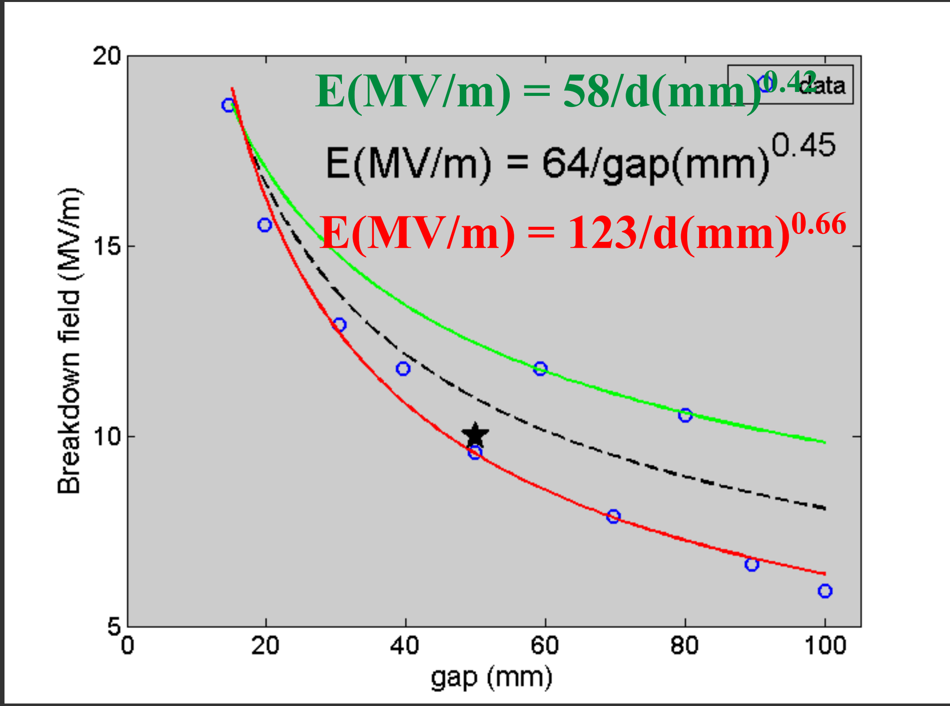
Though not directly related to emittance, high gun voltage is essential from operational point of view

- *Minimize time of flight dependence on the gun voltage fluctuations*
- *To avoid $\beta < 1$ dedicated cavity design*
- *More difficult matching to RF focusing, energy gain depends on transverse position*

Breakdown voltage vs. gap

Adopted from P. Slade "Vacuum interrupter" book





In what follows, the most pessimistic dependence is being used

Transverse focusing

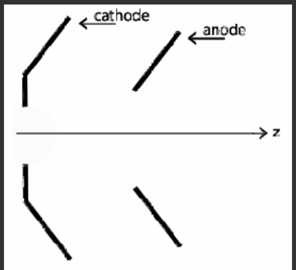
3) *Ideally, gun is to counteract the space charge defocusing*

$$\frac{1}{f_{s.c.}} = -\frac{\Delta p_{\perp}(r)}{r\, p_{\parallel}} = -\frac{I\, gap\, mc^2}{I_0\, r^2\, eV} \frac{1}{\beta_f \gamma_f} \ln \frac{(1+\gamma_i) gap}{(1+\gamma_f) z_i}$$

E.g. V = 500 kV, gap = 5cm
I = 2A, r = 1mm, z_i *= 1mm*

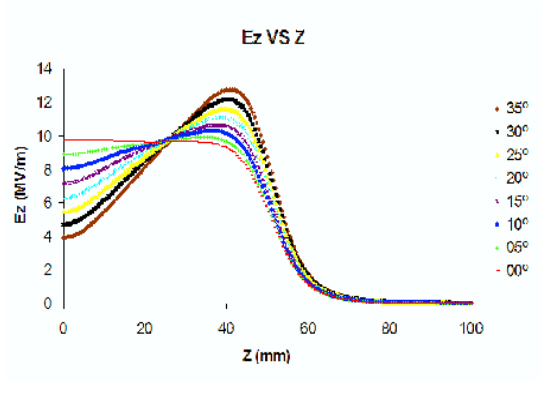
$f_{s.c.} \sim -8$ *cm, very strong (charge dep.)*

Electrostatic focusing



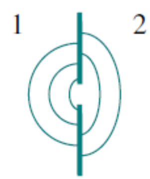
Cathode shaping by Pierce-like shaped cathode

relatively weak, i.e. Cornell gun has 25° and f ~ 55 cm at 500 kV



One of the reasons for its weakness is the anode defocusing

electrostatic aperture



$$f = 4V \frac{1+\frac{1}{2}eV/mc^2}{1+eV/mc^2}\frac{1}{E_2-E_1}$$

E.g. V = 500 kV, gap = 5cm

$\Rightarrow f_{anode} \sim -15$ cm

Magnetic focusing

Pros:

- *no need to sacrifice E_{cath} by Pierce-like shapes, should give higher brightness*
- *can be made as strong as needed and adjusted for different charge per bunch running*

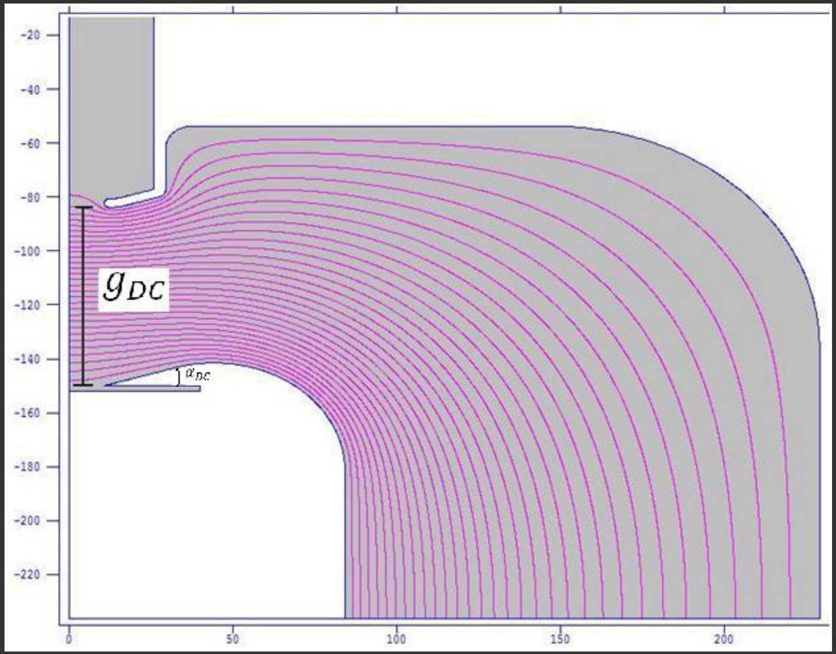
Cons:

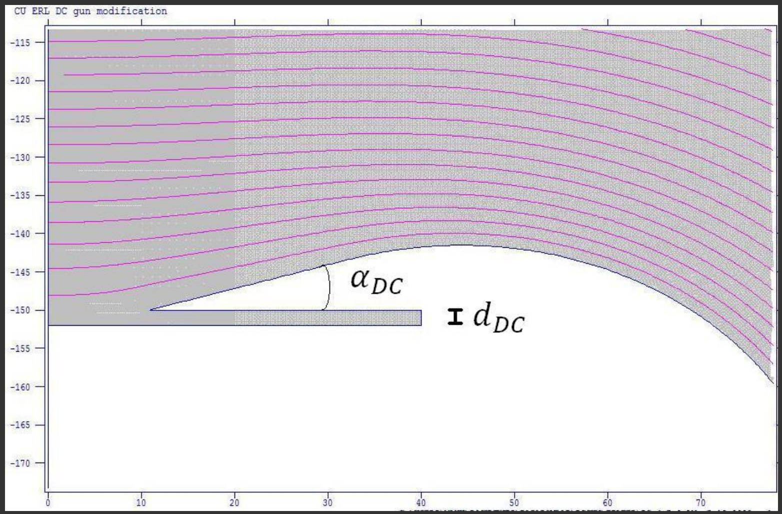
- *DC gun structures tend to be bulky, hard to localize the fields*
- *Need bucking coil to cancel B at the cathode*

Can be done!

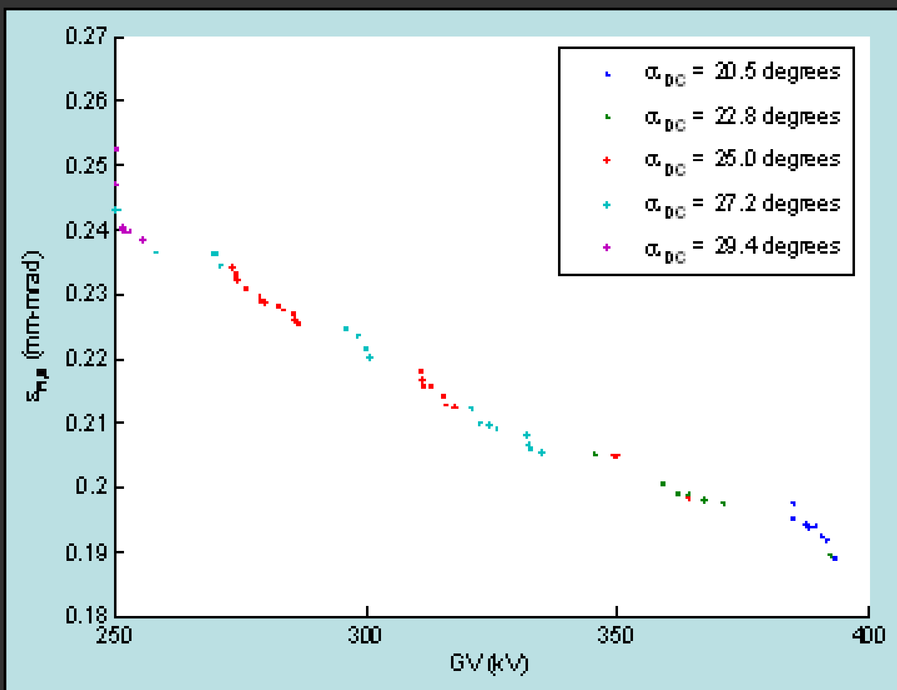
Parametrized geometry

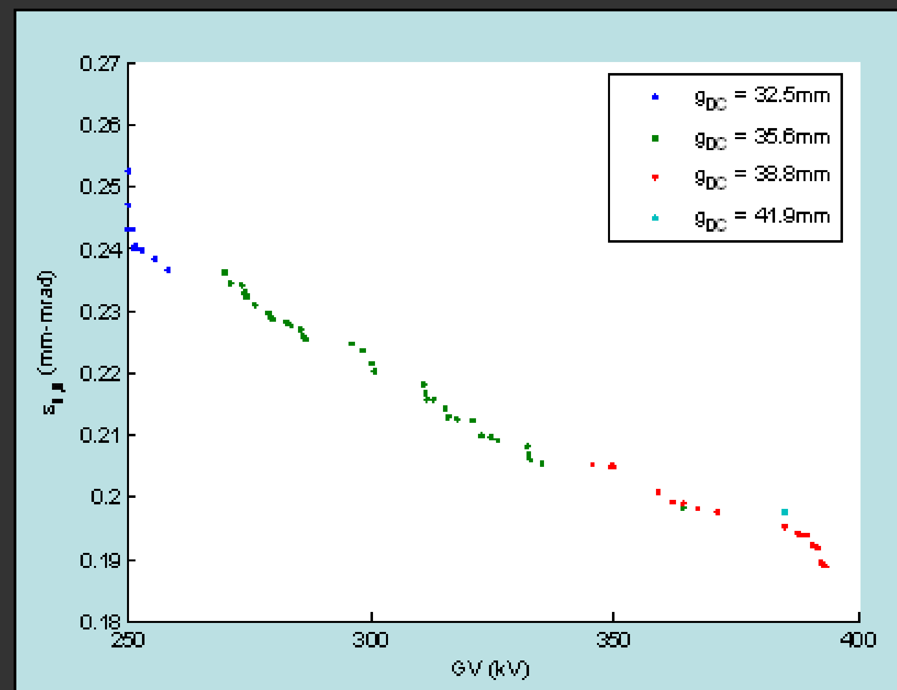
4) Cornell study





Results (80 pC, 1.3 m after the gun)





Results recapped

- ***Relatively weak dependence on voltage: 20% in emittance over 250 – 400 kV range <u>if the gap is made correspondingly small</u> to maximize the cathode field (as limited by the breakdown condition)***
- ***Cathode angles ~25° are near optimum***
- ***Variable recess has a weak effect (~5%) on emittance***

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Ultimate gun?

5)

a) Maximize the electric field at the cathode

b) Have sufficient voltage

c) Provide strong focusing

⇒ Two gap gun with solenoids

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Cathode field ~ 15 MV/m
Total voltage ~ 700 kV
(e.g. 250+450kV with
15 and 50 mm gaps)