Beam-Beam dynamics in the LHeC

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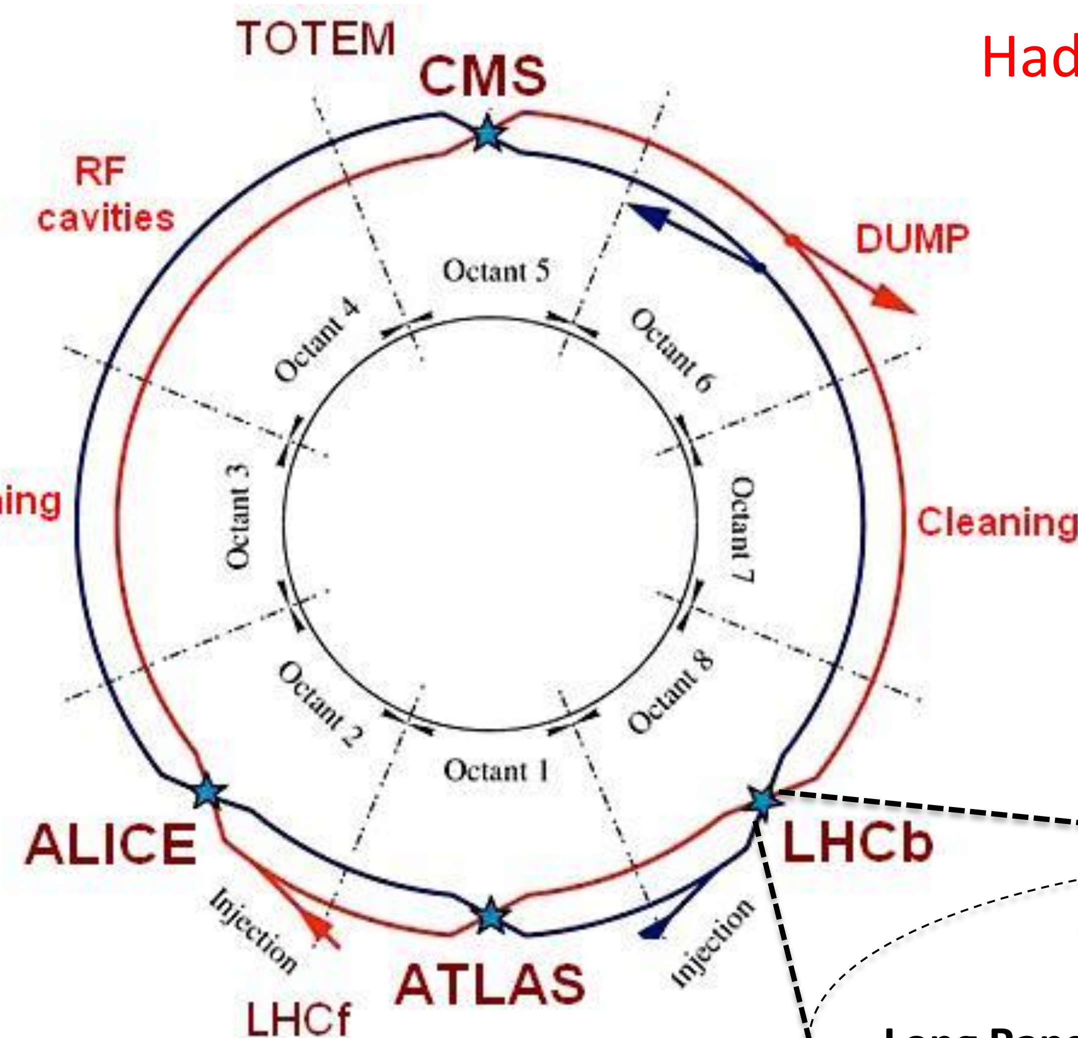
with help from W. Herr, Y. Hao and W. Fischer (BNL)

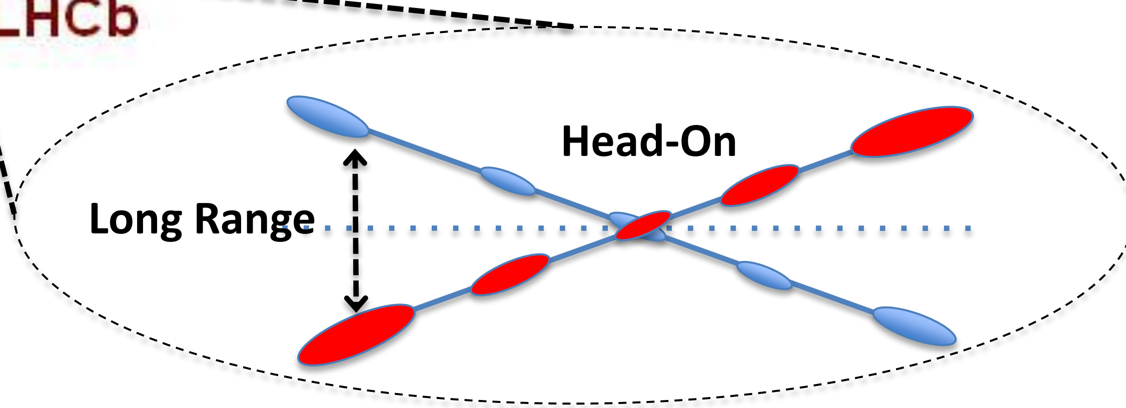
Beam-Beam interactions in the LH~~e~~C



Hadron Colliders:

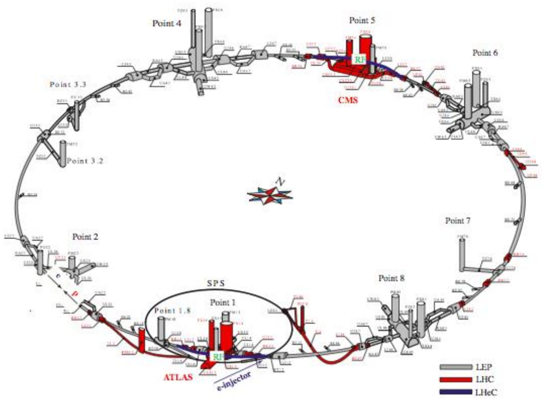
- Beam Losses (dynamic aperture)
- Beam Lifetime
- External noise very important
- Landau damping properties
- Coherent modes
- …

IR: 3 Head-on collisions
30 long-range interaction



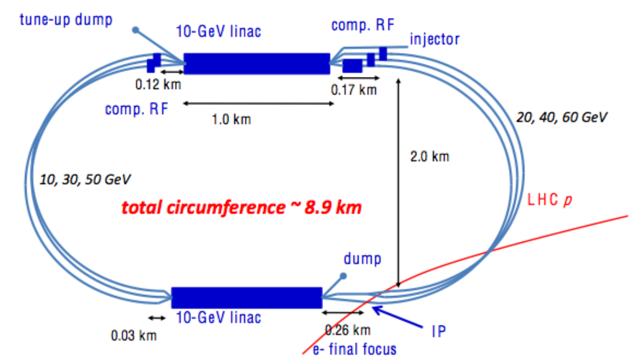
Beam-beam interactions in the LHeC options

RING-RING Option



- Crossing angle needed (S factor 86-75%)
- One head-on interaction at IP
- Long range encounters every 3.75 m in IR
- e-beam acts as noise source

LINAC-RING Option



- No crossing angle
- One head-on interaction at IP
- No Long-range encounters
- e-beam noise source
- No worry of stability of e-beam

LHC pp Beam-beam effects:

2 Head-on collisions & 60 Long-range interactions at least

LHeC Beam-beam complications:

- Large Number of bunches in both beams (2808)

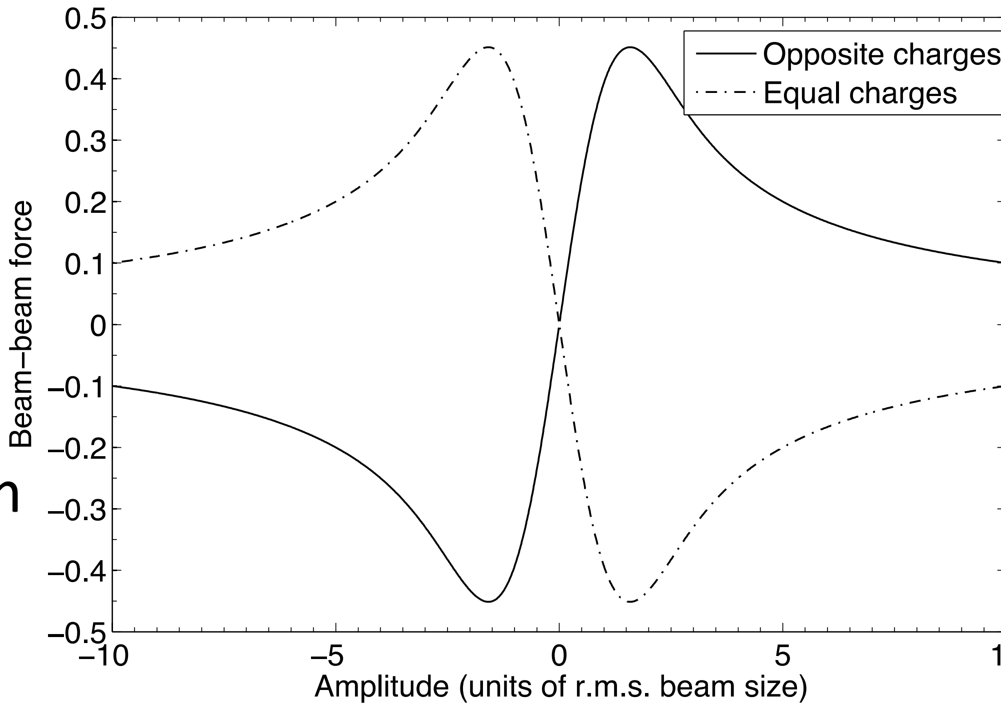
- Simultaneous collisions of ep and pp of one proton beam
  - pp collisions in IR1 and IR5
  - ep collisions at another IR

Different beam-beam properties

- Long term stability of
- proton beams:

dominated by non linear effects

- Long term stability of RR e-beam
- and mismatch of e-beam in LR



Known performance issues :

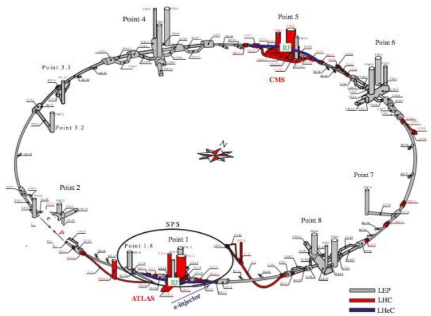
- Optical matching (SPS, Hera and Tevatron experience)
  - ✧ $\sigma_x^e = \sigma_x^p$
  - ✧ $\sigma_y^e = \sigma_y^p$

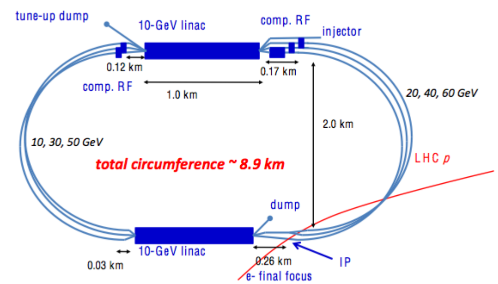
- Since different emittances for p and e then the beta functions at IP have to be different for the two beams (Hourglass effect)
  - ✧ Restricts choice on β_e

- Electron emittance must be controlled (coupling H/V):
  - ✧ Might be ok for RR option
  - ✧ Not obvious for LR option

- ep collision introduces asymmetry HV in Hadrons beam-beam effects

Beam-Beam effects



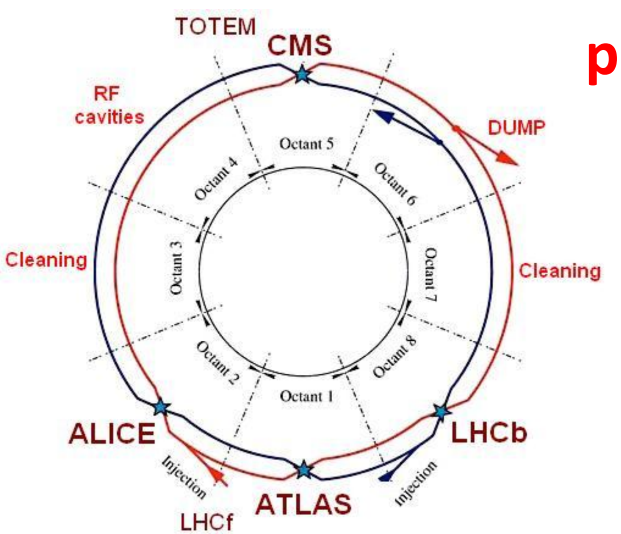


e-beam

- Tune shifts/spread
- Long Range interaction effects
- Noise

e-beam

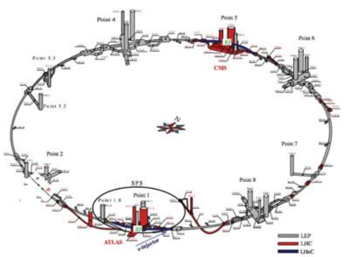
- Tune shift/spread
- Mismatch
- Disruption



p-beam

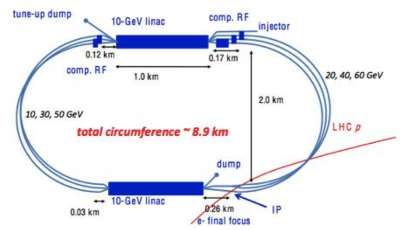
- Tune shifts/spread
- Landau Damping properties
- Long Range interaction effects
- Noise from ep collisions

Beam-beam parameter:



$$\xi^{e,p}_{x,y} = \frac{r_{e,p}}{2\pi} \frac{N^{p,e} \beta^{*e,p}_{x,y}}{\gamma_{e,p} \sigma^{p,e}_{x,y} (\sigma^{p,e}_x + \sigma^{p,e}_y)}$$

IR Option	1 degree		10 degree	
Beams	Electrons	Protons	Electrons	Protons
Energy	60 GeV	7 TeV	60 GeV	7 TeV
Intensity	$2 \cdot 10^{10}$	$1.7 \cdot 10^{11}$	$2 \cdot 10^{10}$	$1.7 \cdot 10^{11}$
β^*_x	0.4 m	4.05 m	0.18 m	1.8 m
β^*_y	0.2 m	0.97 m	0.1 m	0.5 m
ϵ_x	5 nm	0.5 nm	5 nm	0.5 nm
ϵ_y	2.5 nm	0.5 nm	2.5 nm	0.5 nm
σ_x	45 μm		30 μm	
σ_y	22 μm		15.8 μm	
Crossing angle	1 mrad		1 mrad	
$\xi_{bb,x}$	0.086	0.0008	0.085	0.0008
$\xi_{bb,y}$	0.088	0.0004	0.090	0.0004
Luminosity	$7.33 \cdot 10^{32}$ cm^{-2}s^{-1}		$1.34 \cdot 10^{33}$ cm^{-2}s^{-1}	



ep Tune shift 1e-4 on proton beam less than 1% of pp collision effect (LR CdR D. Schulte & Co)

Could become important ingredient to consider when lack of Landau Damping or when pinch effect considered in the e-beam

ep tune shift goes opposite direction respect to pp collisions

BB parameter and Tune Shifts:

Head-on beam-beam parameter achieved so far:

From Experience	LHC pp collisions	LEP (90 GeV) electron
$\xi_{x,y}$	0.07 - 0.017 /IP	0.03 – 0.07 /IP

- Electrons higher than what achieved in LEP (tune shifts of 0.04):

  1 degree option optimistic but significant reduction from dynamic beta and small number of IP can make it feasible

  10 degree option too high tune shift for the electrons

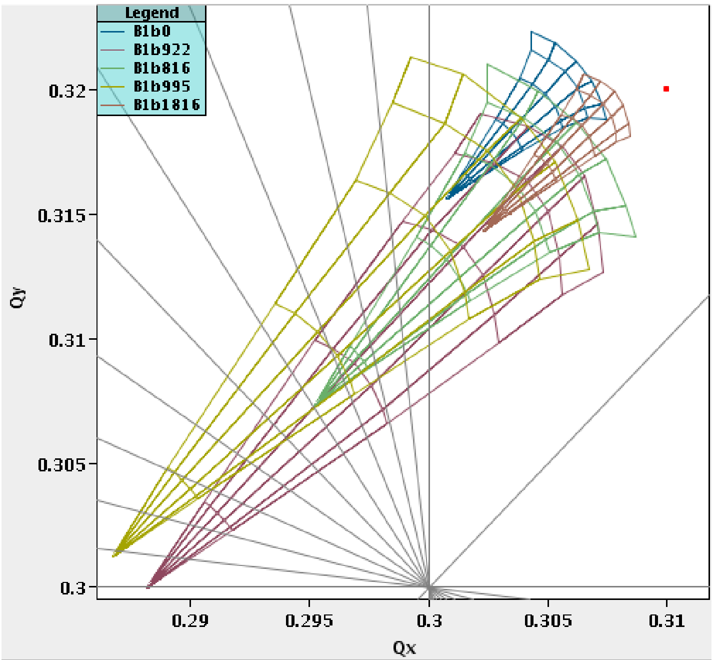
- Protons tune shift from e-beam in shadow of head-on pp collisions and opposite direction (decreases pp tune spread) assuming designed transverse size 0.0001.
  - Pinch Effect can enhance the compensating effect and/or will act differently on particles

Electron effect on protons tune spread is an important ingredient for Landau Damping even if small should be studied in details!

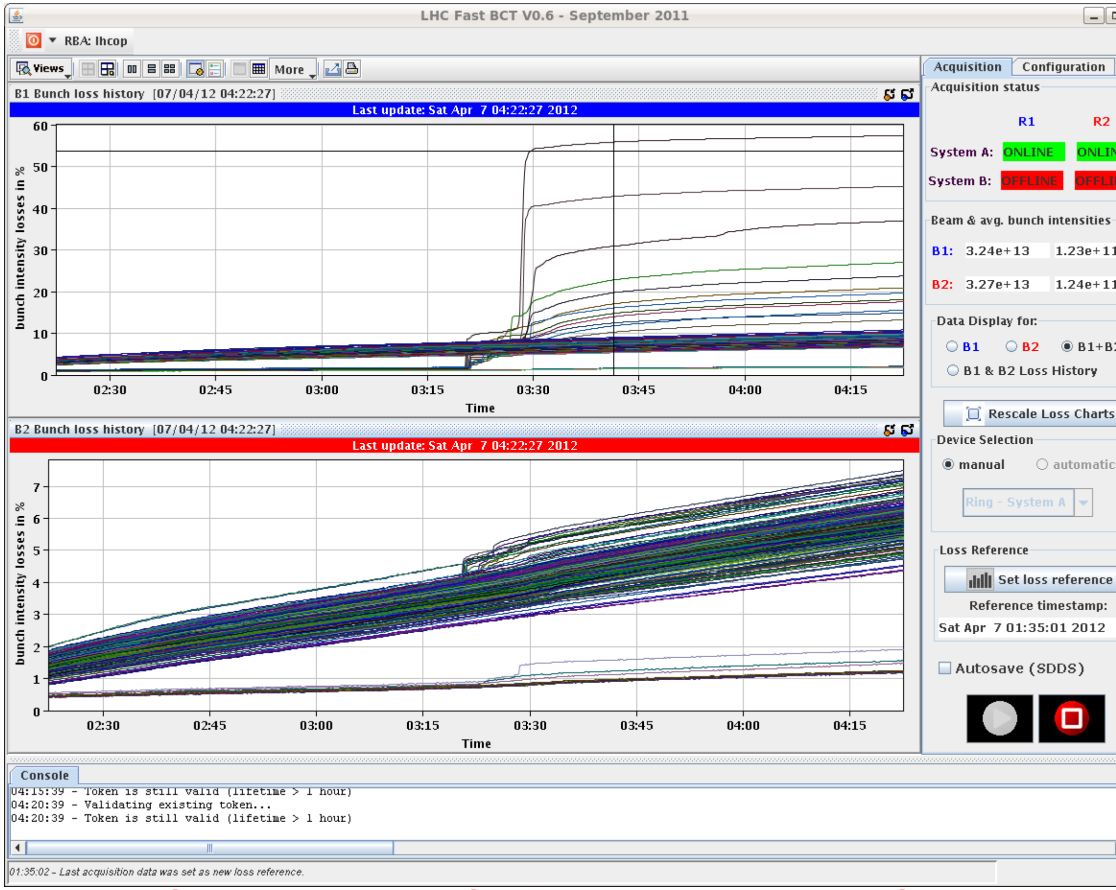
Tune spread and Landau Damping

Head-on beam-beam only sufficient to provide tune spread for Landau Damping at collision energy

If a head-on collision is not guaranteed then lack of Landau damping drives the beam unstable as observed in the LHC 2012 operation



Cortesy of X. Buffat



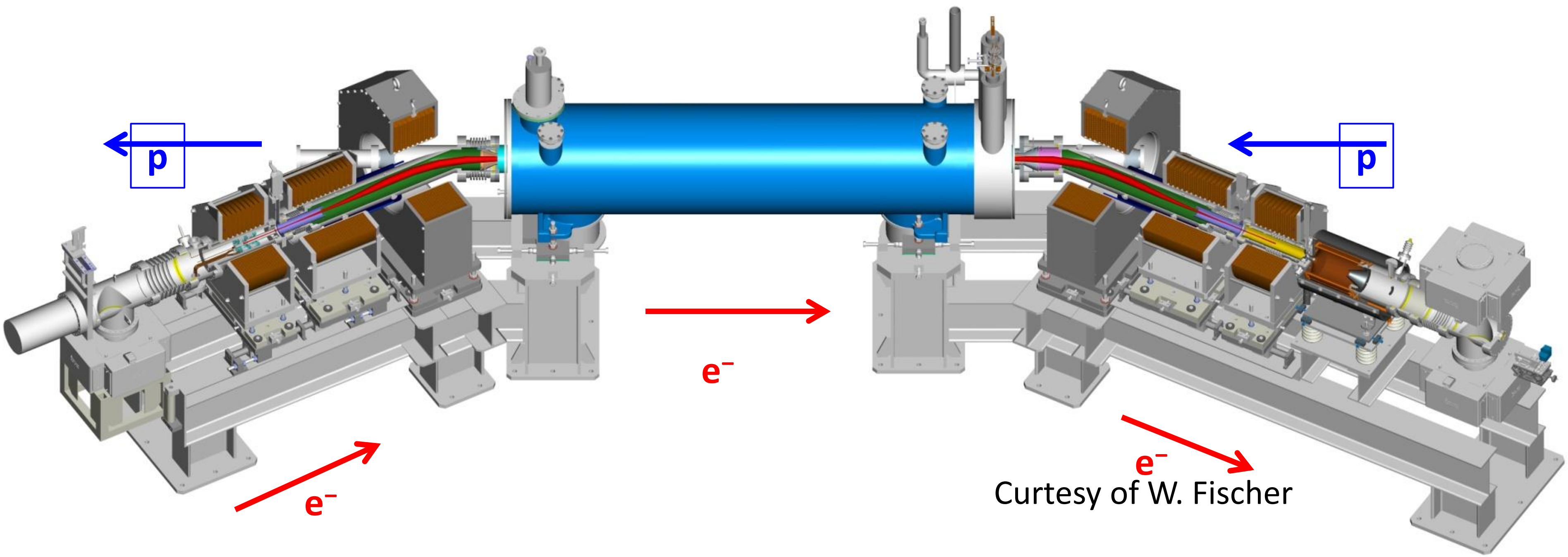
ep collisions compensate a fraction of the spread of pp collisions (as e-lenses)

Experimental studies: e-lenses in RHIC

Perfect test bench to study:

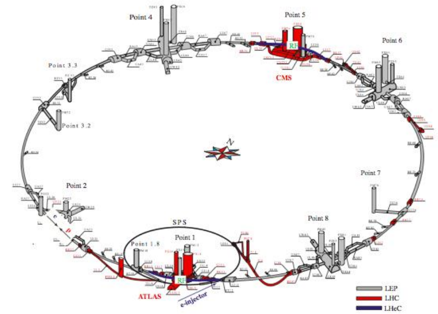
- the interplay between pp and ep collision dynamics
- compensation of tune spread
- effect of transverse mismatch between p and e beams

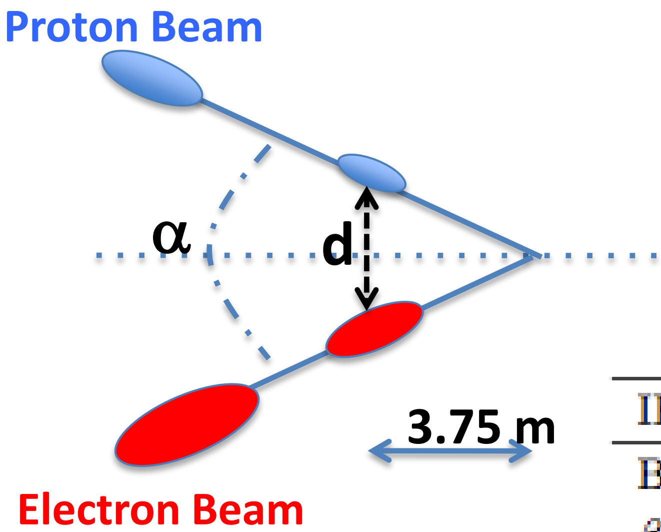
e-lenses at RHIC perfect test bench for studying experimentally the dynamics of



Curtesy of W. Fischer

Parasitic Encounters Separation





Long range encounters every 3.75m in IR

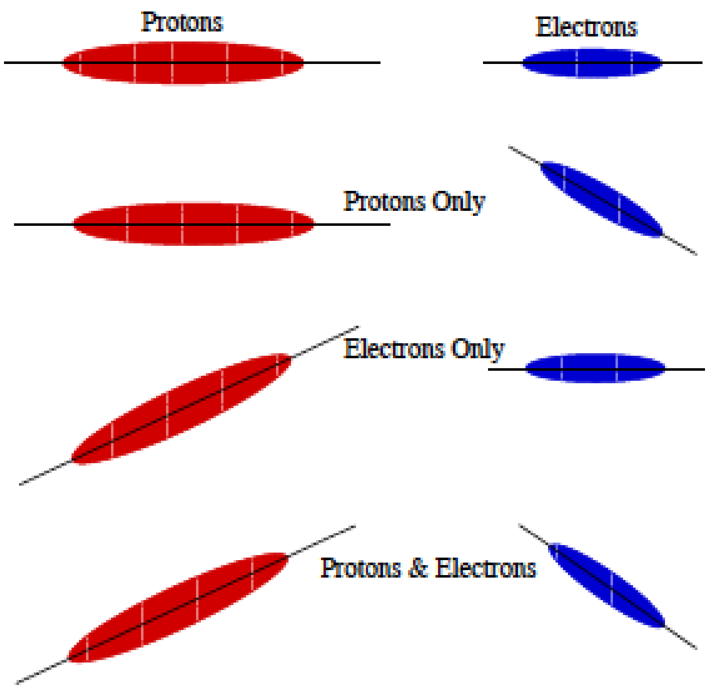
$$d(s) = \alpha \frac{s}{\sqrt{\epsilon \beta(s)}}$$

IR Option	1 degree		10 degree	
Beams	Electrons	Protons	Electrons	Protons
β_x^*	0.4 m	4.05 m	0.18 m	1.8 m
β_y^*	0.2 m	0.97 m	0.1 m	0.5 m
ϵ_x	5 nm	0.5 nm	5 nm	0.5 nm
ϵ_y	2.5 nm	0.5 nm	2.5 nm	0.5 nm
Crossing angle	1 mrad		1 mrad	
d_x	90 σ_p	8.94 σ_e	60 σ_p	6.0 σ_e

- **1 degree option preferable due to larger separation**
- **10 degree option separation smaller, important the interplay with many other LRs**

Dynamic Aperture studies define the effects of the long-range encounters and an optimum set of parameters for the LHeC operation

Increase d or crab cavities?

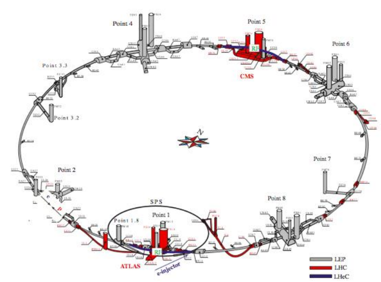


Crab Crossing for the LHeC

R. Calaga, R. Tomás, Y. Sun, F. Zimmermann

June 4, 2010

Scenario	$\Delta L/L_0$ [%]	
	400 MHz	800 MHz
Head-On (with CCs)	88	48
Uncross only e^-	0.7	
Uncross only p^+	88	48
X-Angle (1 mrad)	1.0	



- Increase further the crossing angle and crab cross
- Crab cavities could an option to gain luminosity geometrical reduction due to crossing angle and reduce bb long-range effects

Full study of the effects of crab cavities deflection on the proton beams should be performed

Noise on pp collisions

Hadron colliders performances/luminosity deteriorates in the presence of transverse noise as known from past experience in Spps, Tevatron, RHIC

A source of noise (as the e-beam in LHeC RR or LR options, crab cavities, the 2nd proton beam etc) can lead to:

→ Emittance increase
→ Reduced tune shifts achievable

} **Luminosity deterioration**

- **Analytical models:** simple case cannot describe the LHC/LHeC configurations

- **Numerical models** could have all ingredients (head-on, long-range effects etc) but detailed study does not exist yet (PhD thesis on-going for LHC X. Buffat)

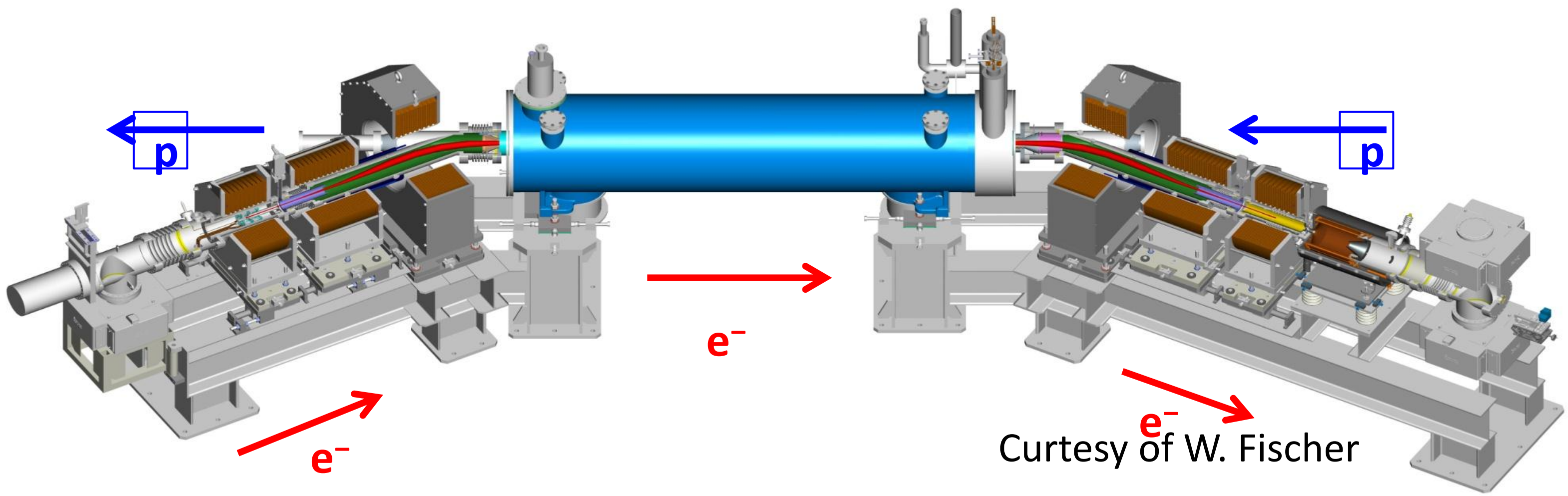
Main components to be addressed:

- Any excitation of one beam will give → dipolar kicks to the other beam
- Jitter of e-beam intensity and/or sizes → quadrupolar error for the proton beam
- Crab cavities (if an option)
- Any other unavoidable source of noise

Detail study is fundamental by use of numerical models for all colliders

LHeC case e-beam is a noise generator for the protons

e-lenses give the possibility to test in controlled way also effects of electron intensity and/or sizes jitters on proton-proton collisions

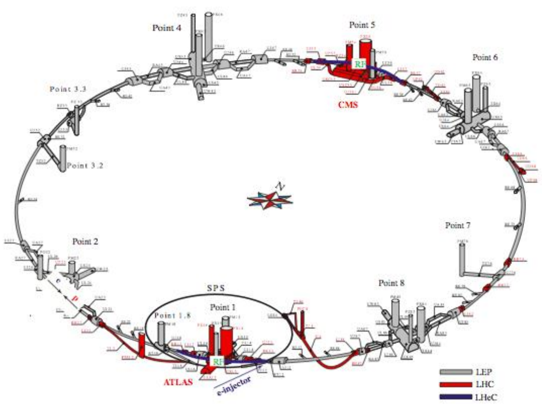


Installation foreseen summer 2012 then commissioning in 2013 run

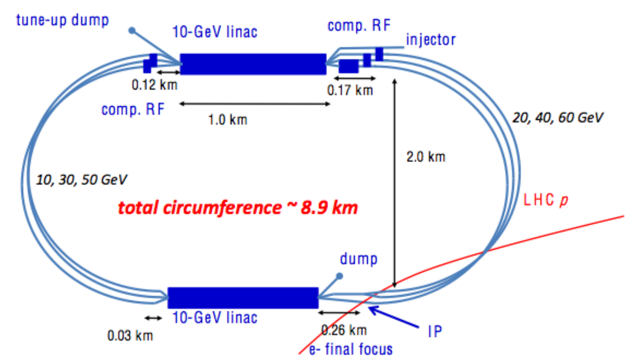
Experimental benchmark of existing models in the LHC or at RHIC with the e-lenses is a key ingredient to define predictive power of numerical tools

Beam-beam issues to be addressed

- Dynamic of pp and ep collisions to be studied self consistently with numerical tools and where possible with experimental studies (RHIC e-lenses)
- Dynamic aperture tracking studies (define best WP and parameters) for the two options
- Detail study on noise effects on the protons by numerical models and where possible experimental benchmark



- Long Range beam-beam effects from RR option
- Multiple bunch effects (colliding with same bunches)
- Long term stability of e-beam



- Effect of pinched e-beam on proton dynamics (tune shift and spread, etc)
- e-beam deflection on p-beam

THANK YOU