ATTEMPT OF A SUMMARY OF

"SIMULATIONS OF E-CLOUD BUILDUP II"

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THANKS TO TOM

MULTIPACTING AND REMEDIES OF ELECTRON CLOUD IN LONG BUNCH PROTON MACHINE

LANFA WANG

LONG BUNCHES (MANY OSZILLATIONS)

ALREADY EXISTING ELECTRONS ARE TRAPPED IN BUNCH

ANALYTIC CALCULATION ⟷ SIMULATION
GOOD AGREEMENT

AT END OF BUNCH ELECTRONS HIT BEAMPIPE

IMPORTANT ARE:

- BEAM INTENSITY
- LONGITUDINAL PROFILE
- TRANSVERSE DISTRIBUTION

REMEDIES:

- SOLENOID
- CLEARING ELECTRODE
  (CAN LEAD TO MULTIPACTING
  IF FIELD IS TOO HIGH)

Energy Gain of multipacting electron &
Mechanism of trailing edge multipacting (SNS/BNL Note 132)

Electron energy when a multipacting electron hit the wall

$$\Delta E = -\frac{1}{2}\sqrt{\frac{me}{2\pi\varepsilon_0}}\beta c\left(a(2\zeta-1)\arcsin\frac{1}{\sqrt{\zeta}} + a\sqrt{2\ln\frac{b}{a}} + \sqrt{2}\zeta\int_a^b\frac{dr}{\sqrt{\ln(b/r)}} - \frac{1}{\sqrt{2}}\int_a^b\frac{1+2\ln(r/a)}{\sqrt{\ln(b/r)}}dr\right)\frac{\partial\lambda}{\partial z}\frac{1}{\sqrt{\lambda}}$$

$$\Delta t = 2.0\sqrt{\frac{\pi\varepsilon_0 m}{\lambda e}}\left(\sqrt{2}a\arcsin\frac{1}{\sqrt{1+2\ln(b/a)}} + \int_a^b\frac{dr}{\sqrt{\ln(b/r)}}\right)$$

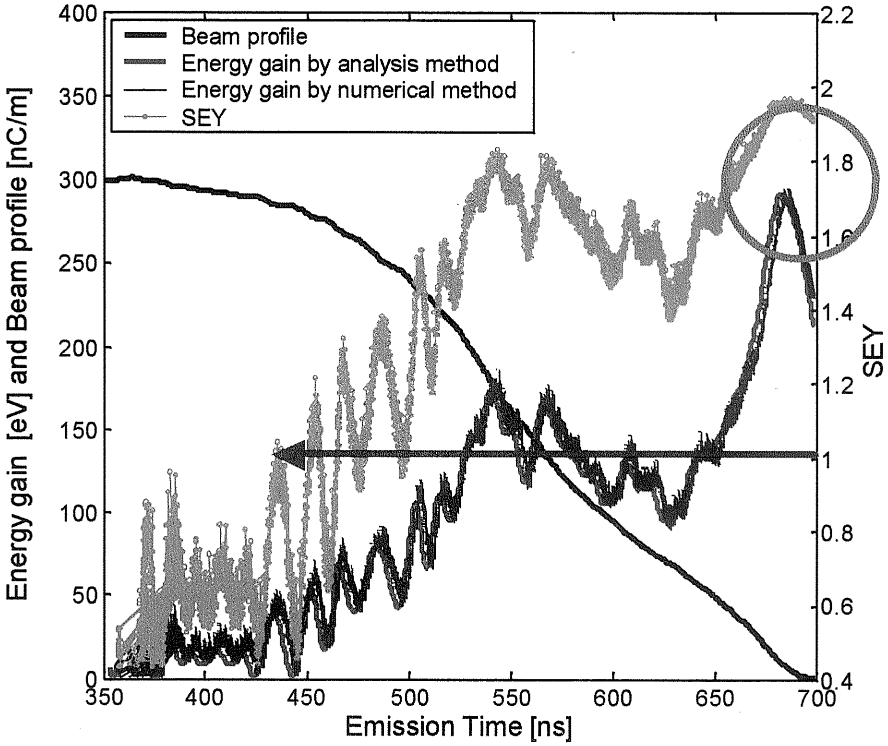
Also see other expressions by M. Blaskiewicz, J. Wei et. al

a: beam size, *b*, chamber radius, λ is beam line density $\zeta = 1 + 2\ln(b/a)$

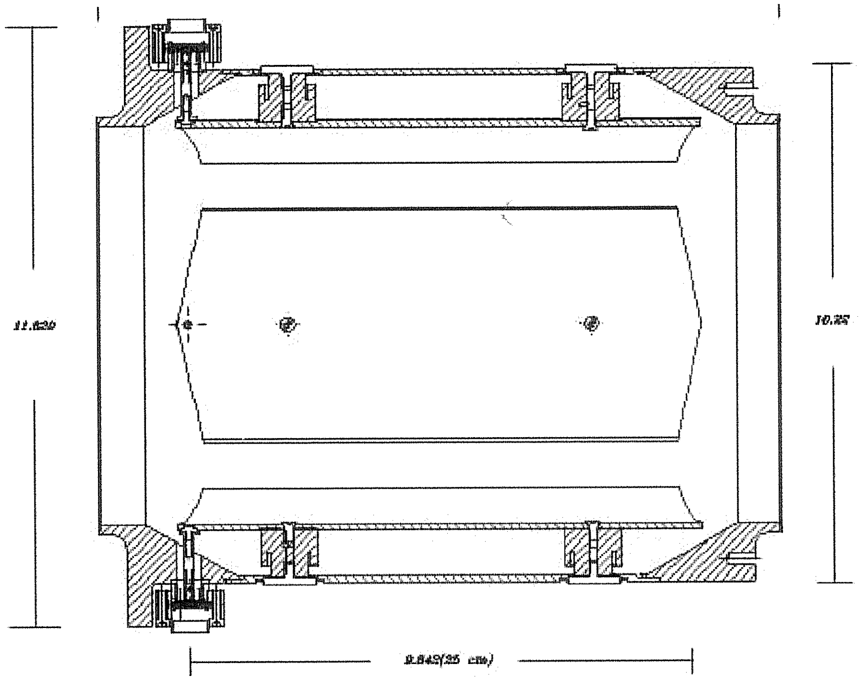
Longitudinal beam profile factor

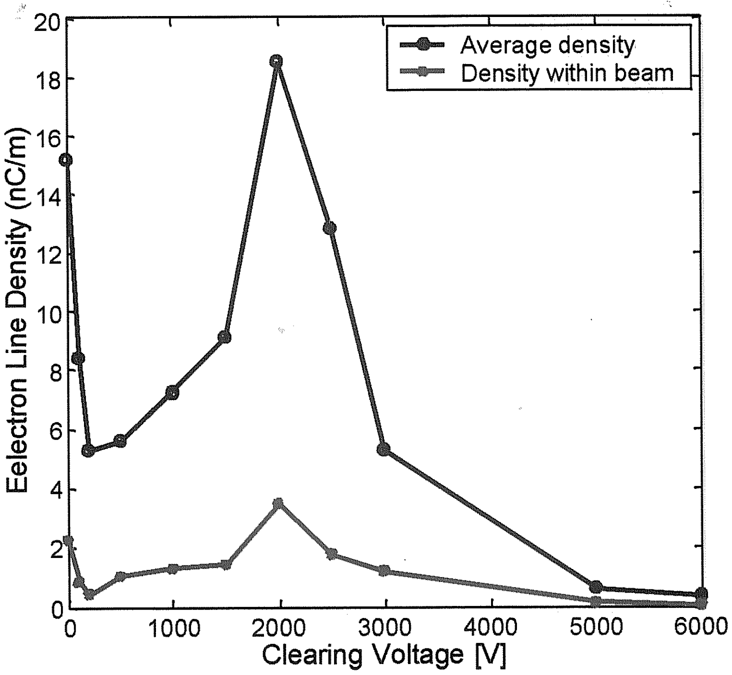
$$Factor_{profile} = -\frac{\partial ?}{\partial z}\frac{1}{\sqrt{?}}$$

- Good agreement with numerical method
- Calculated SEY can be used to predict the multipacting directly
- Adiabatic motion and Energy gain can explain the mechanism of "trailing edge multipactor"



Electrode clearing effect vs. Clearing voltage (PRSTAB, Vol7:034401,2004)





e-cloud density vs. clearing fields

- **Weak field(~200V) is very helpful**
- Strong multipacting at 2kV, which could be stronger than zero field case
- Cooperation with LANL PSR

ELECTRON - CLOUD MODULE FOR THE ORBIT CODE

ANDREI SHISHLO

INTEGRATION OF ELECTRON CLOUD INTO ORBIT

ORBIT IS A PARALLEL ACCELERATOR CODE

IMPLEMENTATION IN C++

SELF CONTAINED MODULES

WELL DEFINED INTERFACES

~~EXTEN~~ EXPANSIBLE VIA

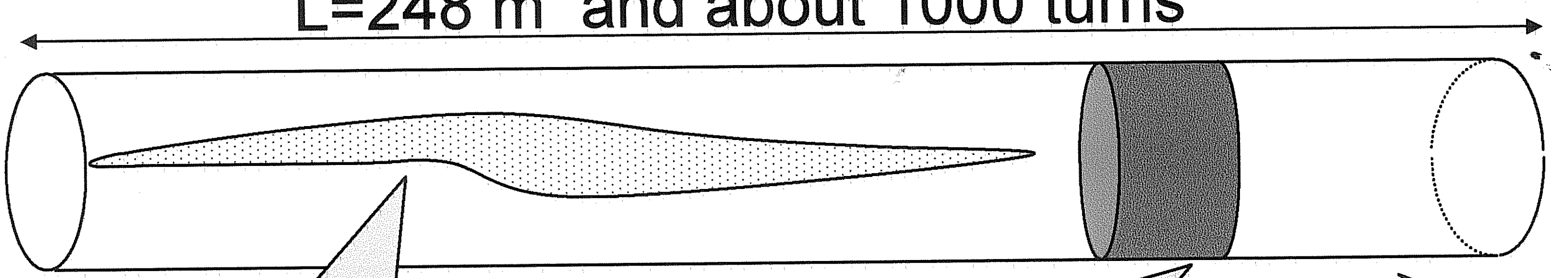
FIELD SOURCE CLASS

SURFACE CLASS

PROTONS ARE DISTRIBUTED ON CPUs (SLICEWISE).

INITIAL BENCHMARKS HAVE BEEN PERFORMED

Simulation Approach



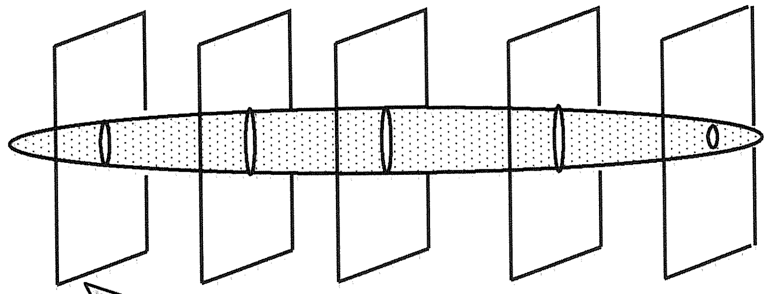
L=248 m and about 1000 turns

Proton Bunch

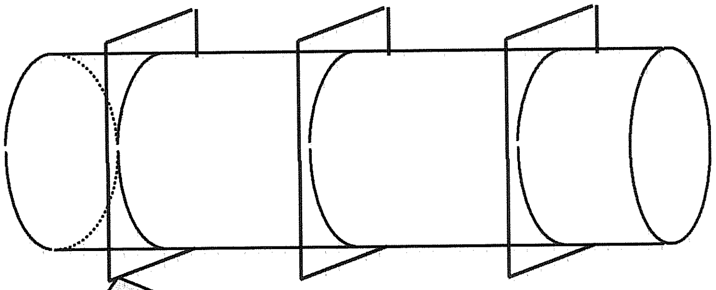
Electron Cloud Region

Pipe

- We have to simulate a building up an electron cloud, its dynamics, its effect on a proton bunch during the whole accumulation period or at least for several turns to detect the development of instability.
- We are going to use PIC method for both p-Bunch and e-Cloud.

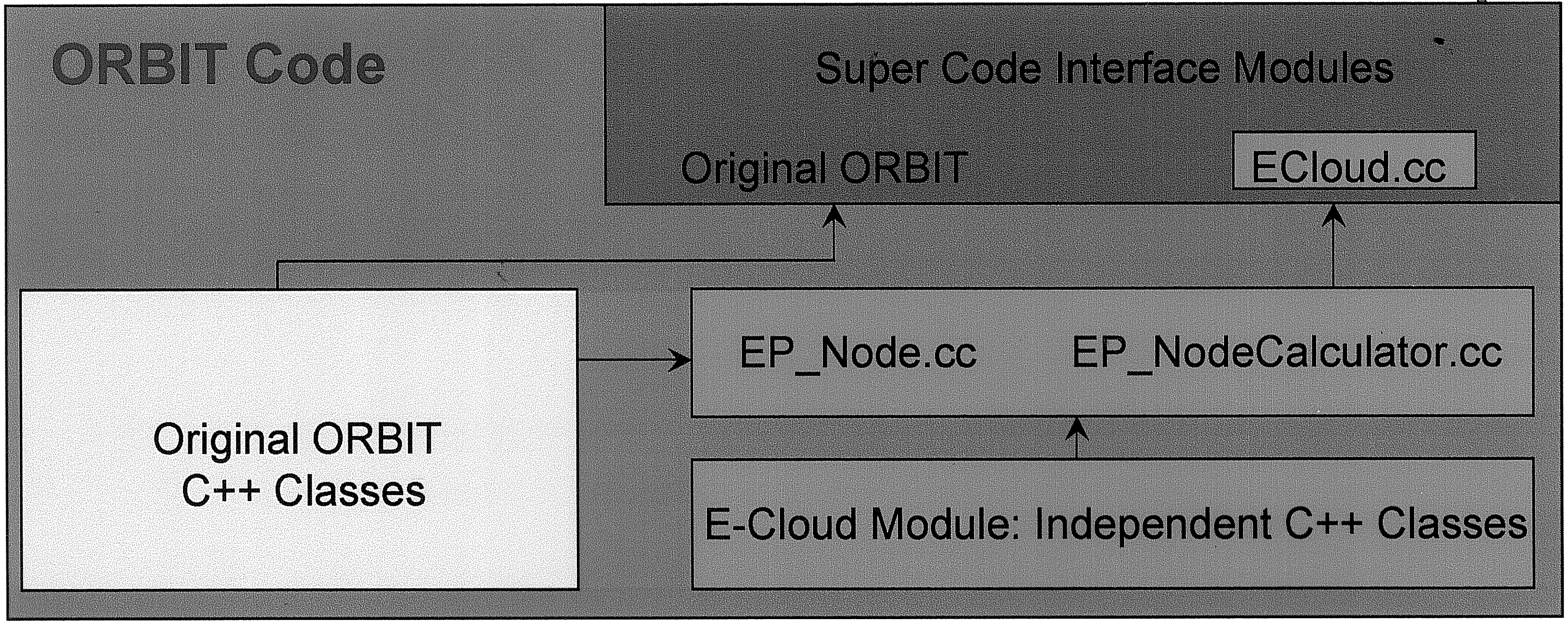


Proton beam 3D SC potential grid



Electron Cloud Grids with few (may be only one) longitudinal slices

E-Cloud Module in the ORBIT Structure



▨ - ORBIT Electron Cloud Module

- The ORBIT E-Cloud Module is a collection of C++ classes. Only three classes connect the E-Cloud module with the original ORBIT code, so the module can be easily modified to use in other accelerator code or independently.
- The special efforts have been made to provide the possibilities for an extension of existing classes and improvement of the models.

SIMULATION OF E-CLOUD USING ORBIT: BENCHMARKS AND FIRST APPLICATION

YOICHI SATO

FOCUS ON BENCHMARKING

SURFACE REFLECTION BASED ON
FURMAN / PIVI
($\delta = \delta_{el} + \delta_{rd} + \delta_{ts}$)

→ GOOD AGREEMENT

TRANSVERSE PROTON ACCELERATION

→ GOOD AGREEMENT

GROWTH RATE FOR CENTROID MOTION

→ REASONABLE AGREEMENT

PSR BUNCHED BEAM NEXT

80'/TURN 16 CPU's

Two stream model in ORBIT, cont.

To reduce the calculation time, we adopt the periodic structure of L=248m/178=1.393m having 20 longitudinal nodes. $N_p = \lambda_p L = 3.241 \times 10^{12}$

Initial proton bunch

KV distribution (R_p=30mm) –needs **very** (32 points) symmetric structure

0.01mm centroid modulation (slow wave) in vertical direction

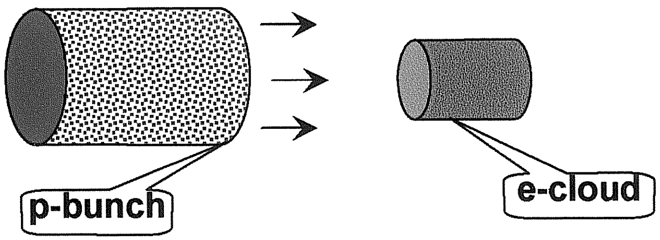
more than 400,000 macroprotons to satisfy at least 10 particles/grid-cell

Initial electron cloud

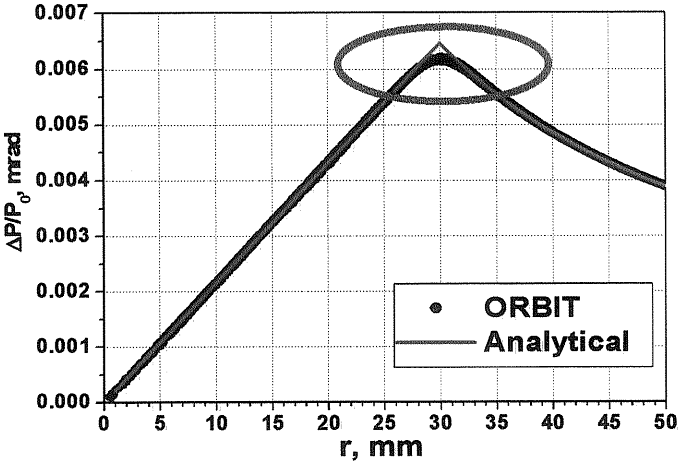
KV distribution (R_e=26mm) –needs to receive linear force inside p-bunch

400,000 macroelectrons with $\lambda_e = \eta \left(\frac{R_e}{R_p}\right)^2 \lambda_p$

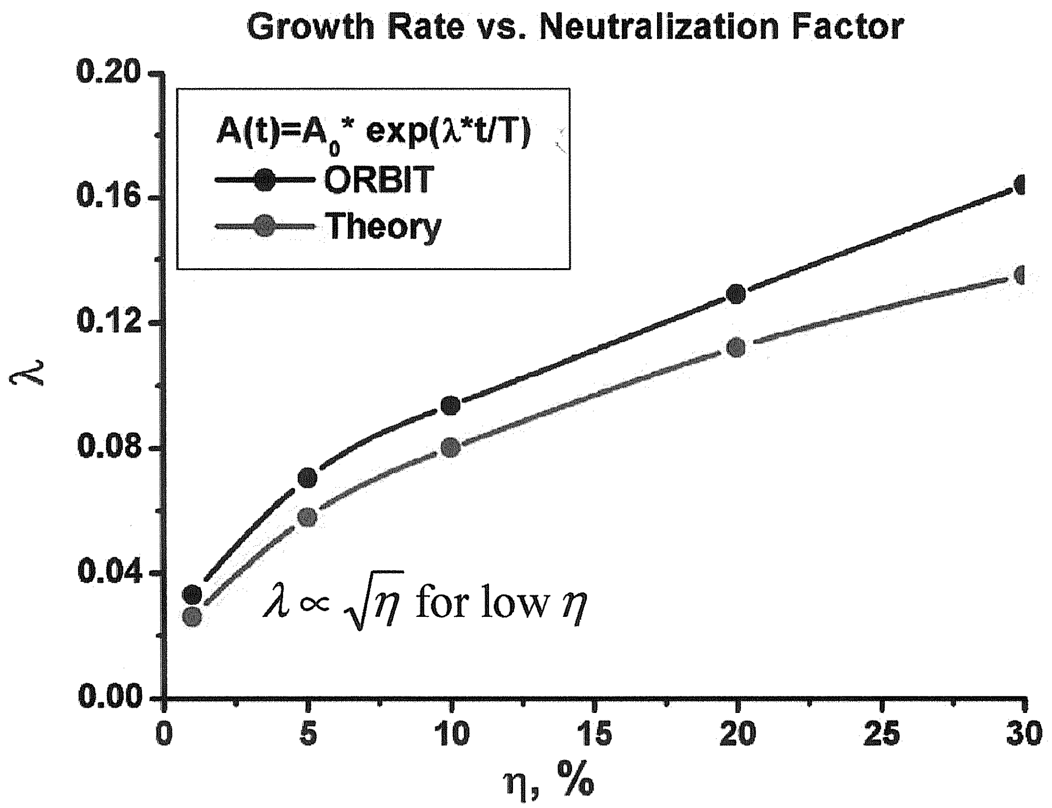
$\left(A_e / A_p\right)_{\eta,\text{ growth mode}} \times 0.01\text{mm}$ centroid modulation in vertical direction



The change in the transverse momentum of protons is in perfect agreement with analytic calculations except for the round shoulder



Two stream benchmark (ORBIT Simulation), cont.



The ORBIT growth rate is about 20% lager than the theory.

$$\frac{1}{\tau} \approx \frac{Q_p \omega_0}{2} \sqrt{\frac{Q_e}{|n - Q_e|}} \approx \frac{Q_p \omega_0}{2} \sqrt{\frac{Q_e}{Q_\beta}} \propto \sqrt{\eta}$$

Initial centroid modulation is for [Re=Rp=30mm] However, we use Re=26mm to ensure linear force

Each proton spends outside of the e-cloud in some part of its trajectory

ENERGY SPECTRUM OF ELECTRON CLOUD WITH SHORT BUNCH

LANFA WANG

ELECTRON CLOUD CAN SHOW DIPS IN ENERGY SPECTRUM

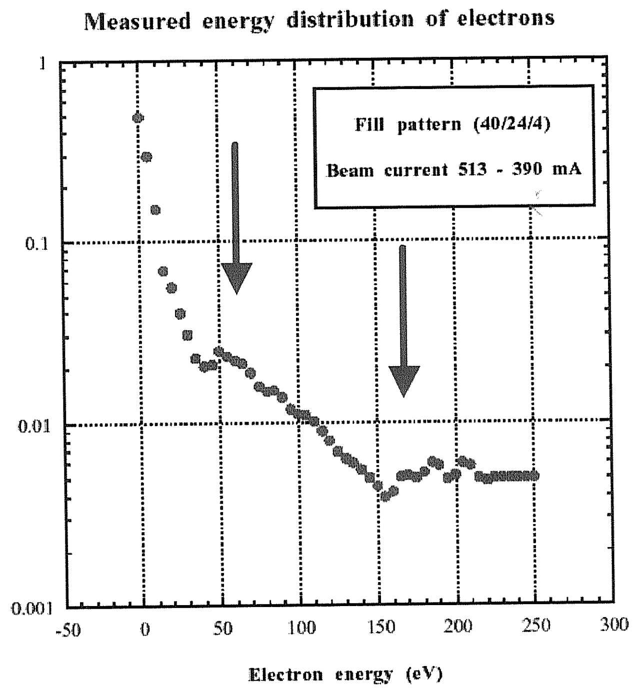
SIMULATION SHOWS THE STOP BANDS ARE DUE TO MULTIPLE BUNCH PASSES DURING ELECTRON OSZILLATION

STRONG DEPENDENCE ON

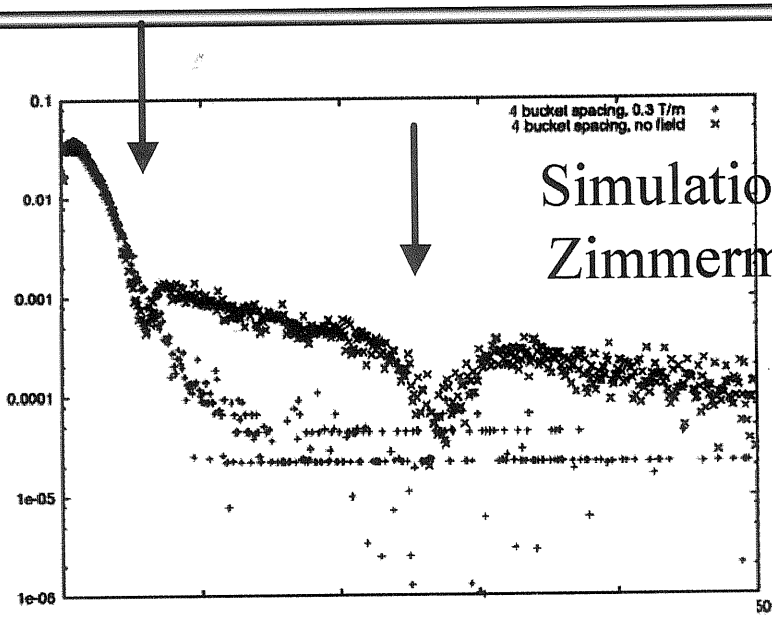
GEOMETRY

BEAM PARAMETERS

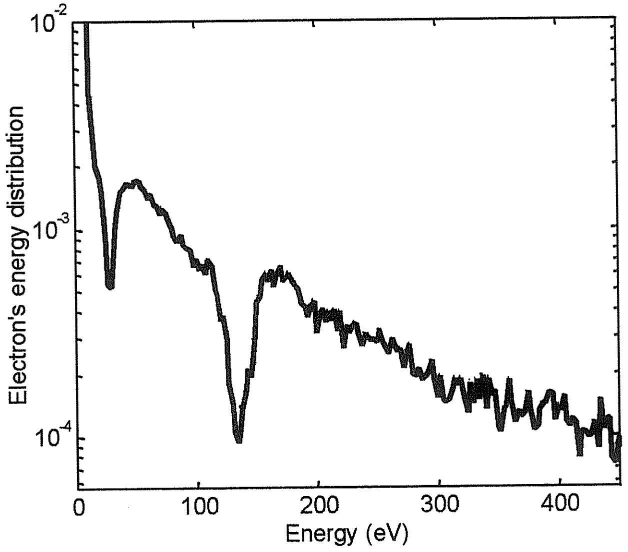
KEKB



Exp. Fukuma



Simulation, F. Zimmermann



Simulation, L.Wang

SOLENOID EFFECTS ON ELECTRON CLOUD

LANFA WANG

WEAK SOLENOIDS CAN SUPPRESS MULTIPACTING

SHORT BUNCHES

LONG BUNCHES

KEEPS ELECTRONS CLOSE TO SURFACE

MORE FREQUENT HITS (LONG BUNCH)

HOMOGENEOUS FIELD IS BEST

REALISTIC FIELDS ARE WORSE

OPPOSITE SIGNS ARE EVEN WORSE

ELECTRONS ARE TRAPPED IN SOLENOIDS

EXPERIMENT DEMONSTRATES SUPPRESSION >50 (PSR)

ELECTRON CLOUD GIVES RISE TO WAKEFIELD

TWO MODES EXIST

BOUNCE FREQUENCY
ROTATION FREQUENCY

KEKB:

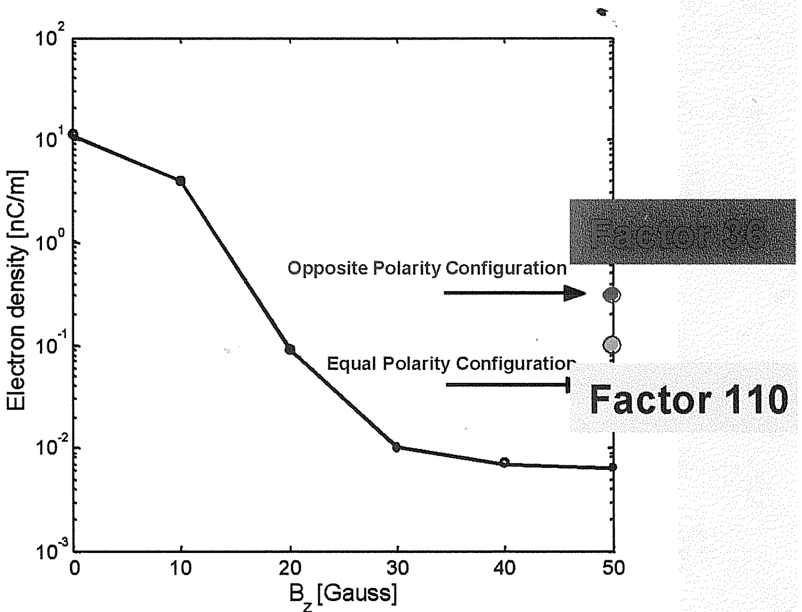
COUPLED BUNCH INSTABILITY CHANGES

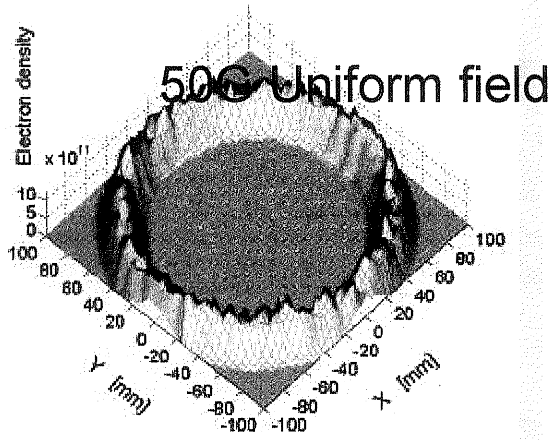
- LOWER MODES
- LESS EXCITATION

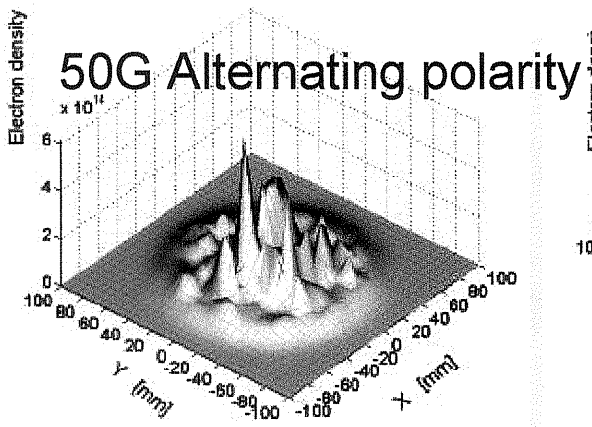
WAKE DEPENDS ON BEAM PARAMETERS

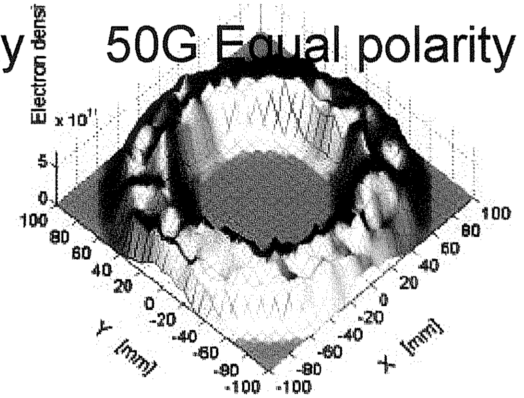
The effect of Solenoid configuration effect--- (SNS)

- The more uniform the solenoid field, the more effective the confinement.
- No Multipacting+zero central density+low level heating

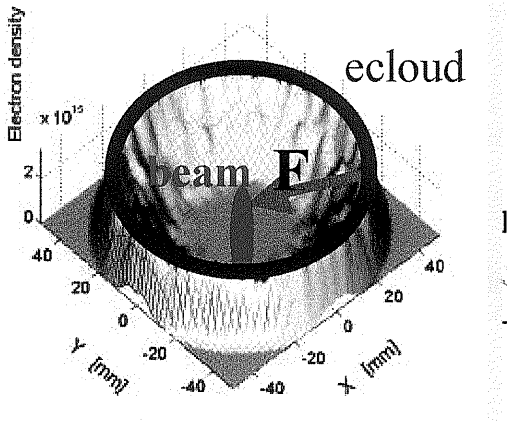


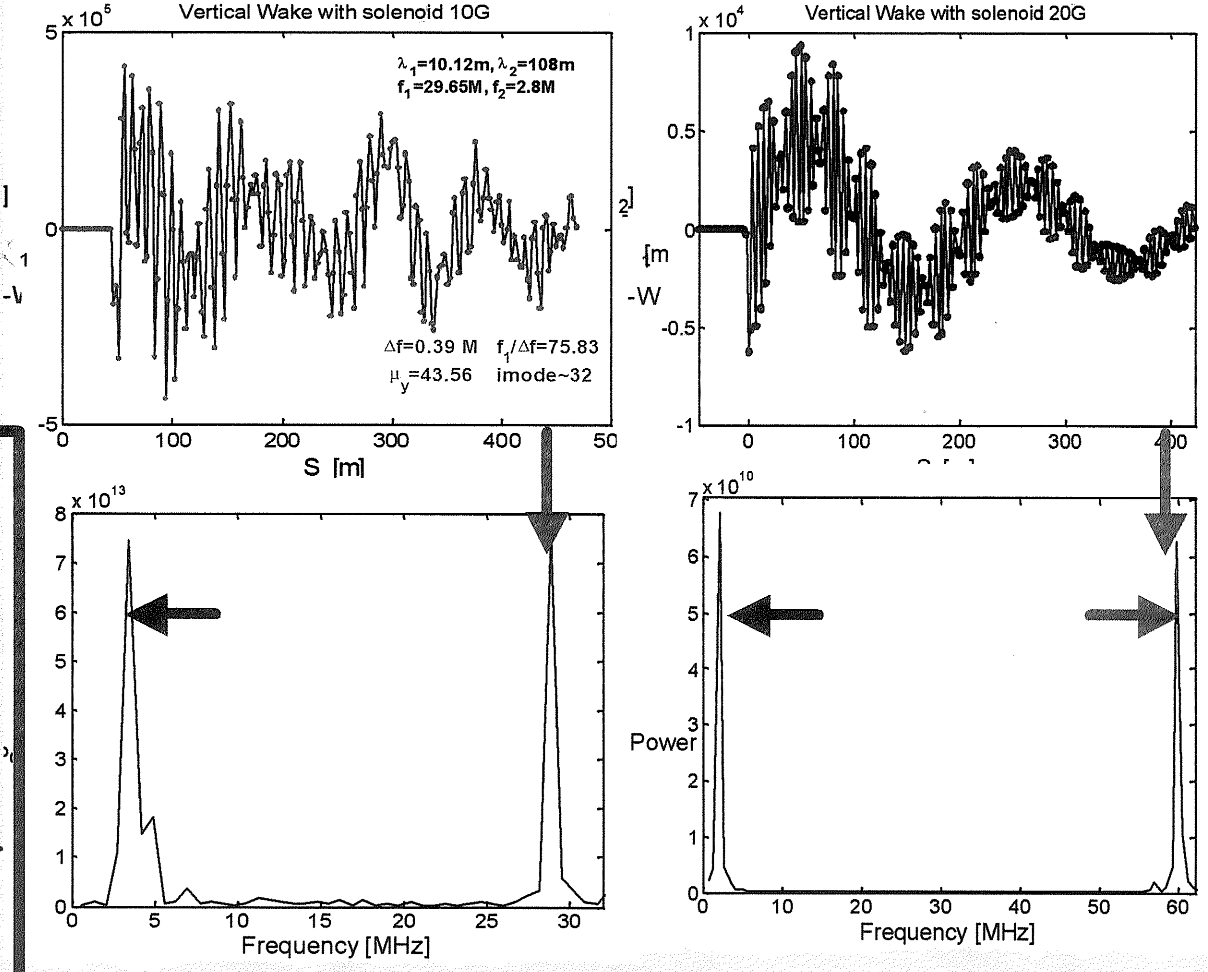

50G Uniform field


50G Alternating polarity


50G Equal polarity

Long range wake of electron cloud with solenoid (KEKB)





Wake has two Modes:

One depends on the electron bounce frequency. The frequency of this mode usually decreases when solenoid fields increase.

Another one comes from the gyration motion of electrons

$$f_c = \frac{eB}{2\pi m_e}$$

B=10G $N_p=3.3\times10^{10}$, 8ns spacing B=20G

MODELING ELECTRON CLOUD EFFECTS IN HEAVY ION ACCELERATORS

RON COHEN

BEAMLINE FULL OF QUADRUPOLES

ELECTRONS CAN LEAVE QUADS IN PULSE

IONISATION + ION LOSSES → ELECTRONS

BASED ON WARP

SCATTERED IONS ARE IMPORTANT

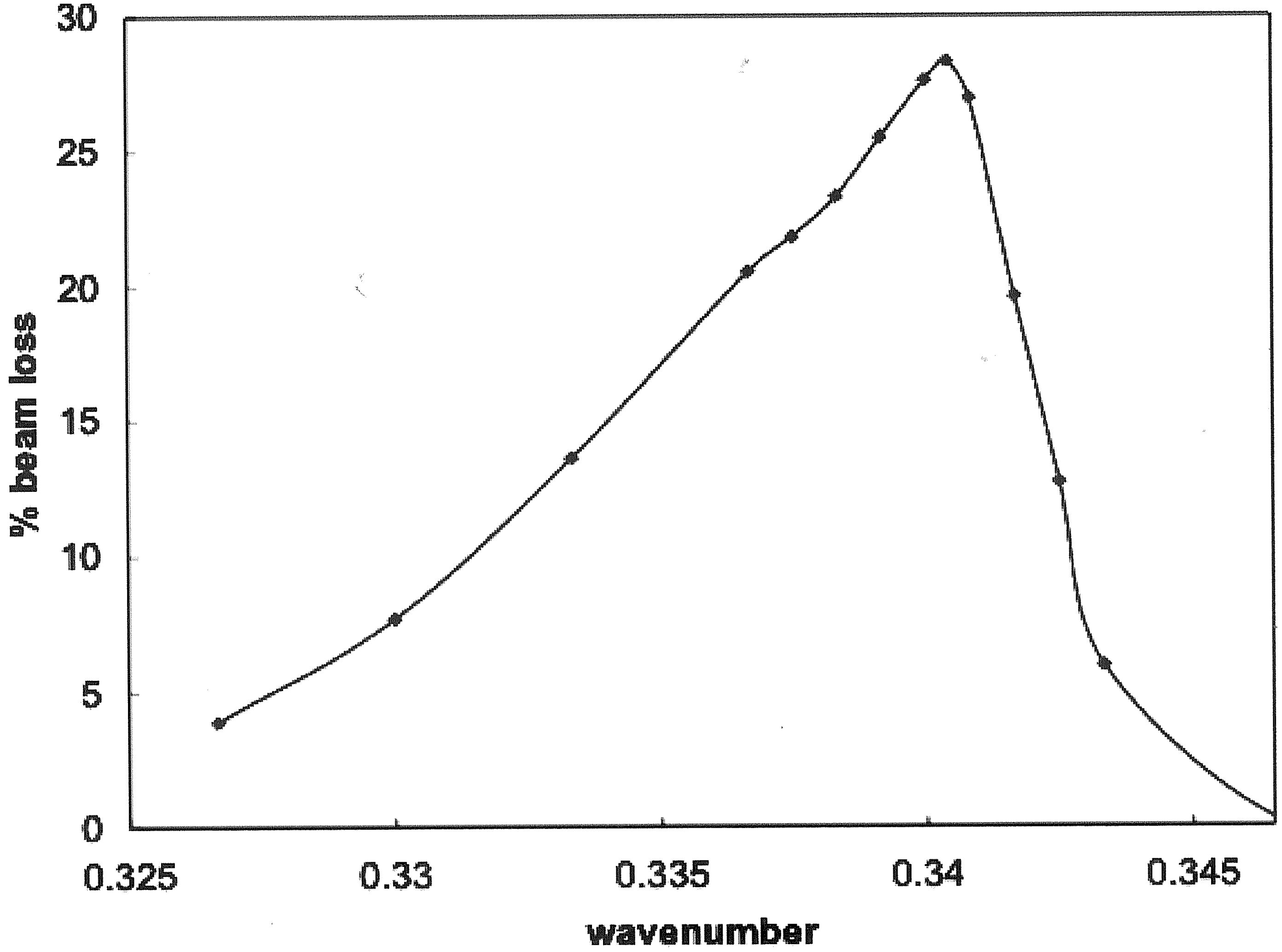
SIMULATIONS WITH CLOUD:

- CONSTANT → LITTLE EFFECT
- RANDOM → SIGNIFICANT LOSS
- OFFSETS → LOSS + EMITTANCE GROWT
- VAR. SHAPE → IN BETWEEN
- RES. ELLIPTICITY → EMITTANCE GROWTH

MODULATION CAN GIVE MILD INSTABILITY

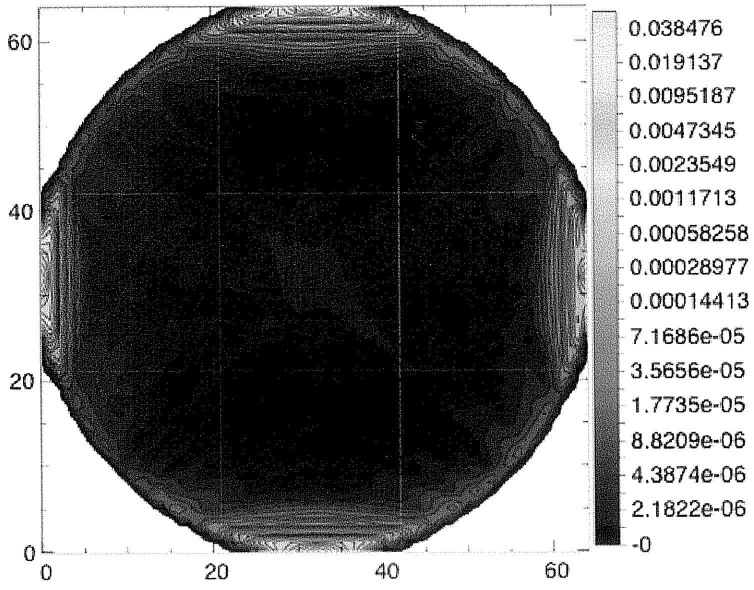
INTERPOLATED MOVER
→ MUCH FASTER

RESONANT perturbations are more damaging: 0-10% sinusoidally varying n_e resonant with breathing mode

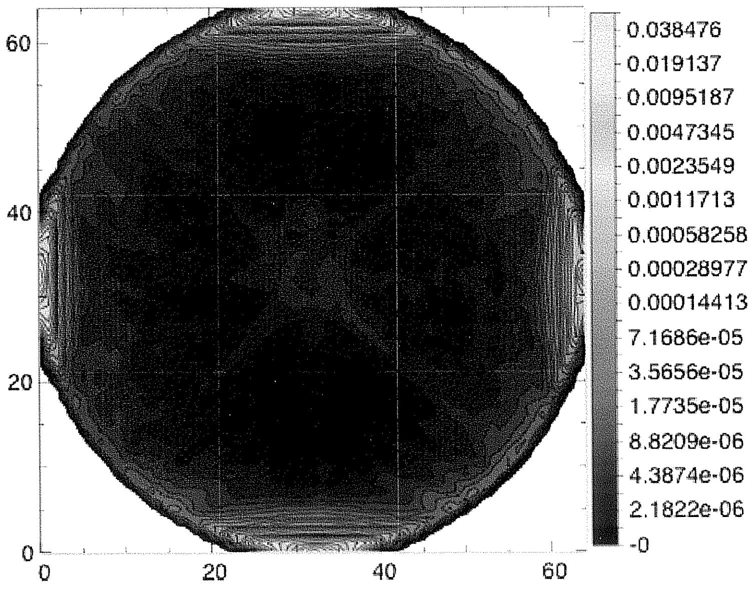


Interpolated model reproduces the e-cloud calculation in < 1/25 time

- Compare full-orbit model, $\Delta t = .25/f_{ce}$, with interpolated model with Δt 25 times longer



Full-orbit



Large-timestep interpolated

THE CMEE LIBRARY FOR NUMERICAL MODELING OF ELECTRON EFFECTS

PETER STOLTZ

COMPUTATIONAL MODULES OF ELECTRON EFFECTS

MAKE USEFULL ROUTINES AVAILABLE

→ SAVES WORK (TESTING)
→ BETTER COMPARABILITY
→ SIMPLER UPDATES
→ BETTER SIMULATIONS

ROUTINES AVAILABLE:

POSINST SECONDARY ELECTRONS

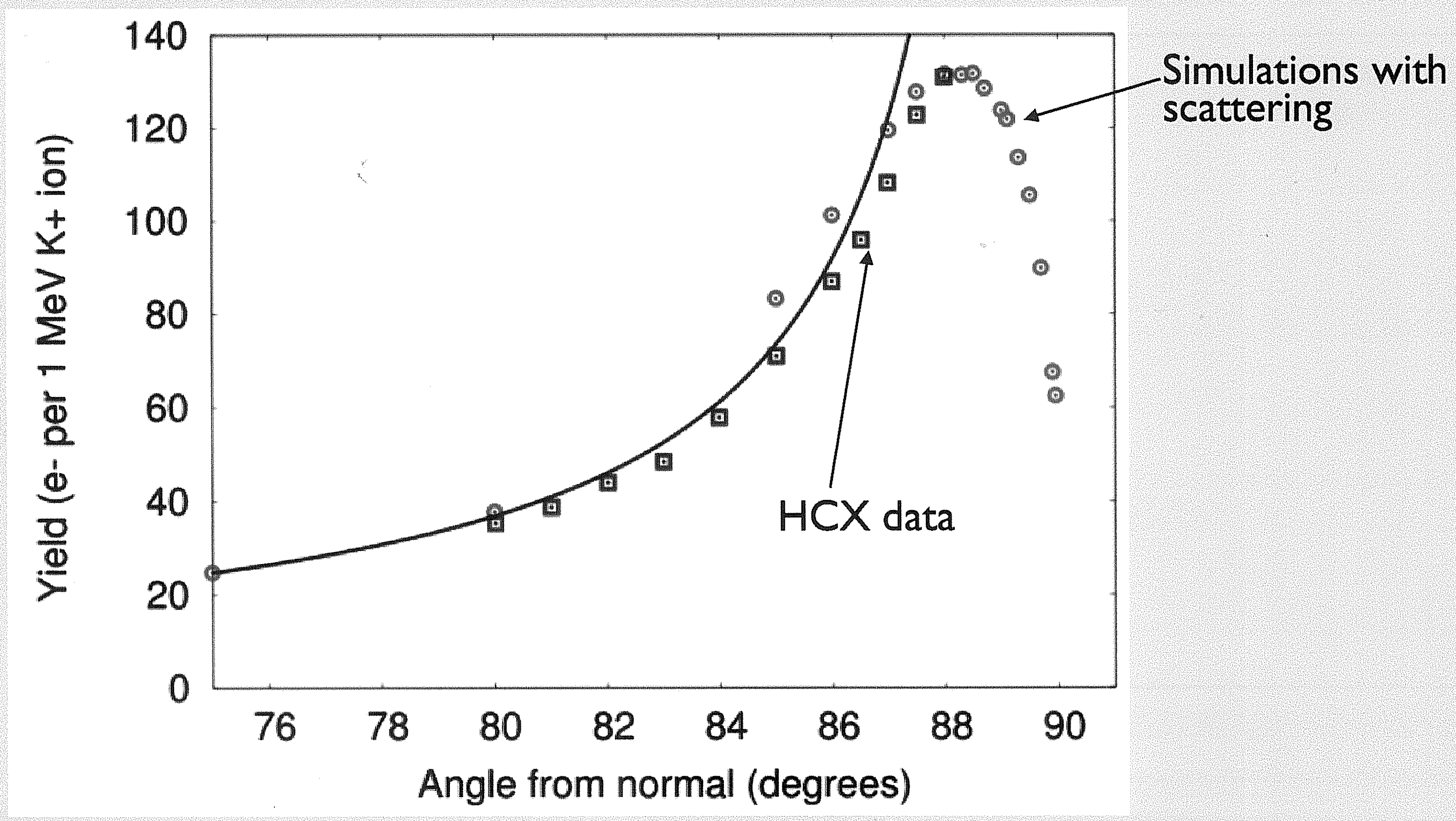
TO COME:

ION-INDUCED ELECTRONS
NEUTRAL DESORPTION
IMPACT IONISATION
ION SCATTERING
ENERGY LOSS

EASY INSTALLATION

C++, FORTRAN PYTHON TO COME

Ion scattering is one way to explain grazing electron yields



HCX data

Simulations with scattering

USE OF MAPS FOR EXPLORATION OF ELECTRON CLOUD PARAMETER SPACE

UBALDO IRISO

AIM: OPTIMISATION OF BUNCH PATTERN IN RHIC

FULL SIMULATION VERY TIME CONSUMING

TRICK: USE MAPS FROM SIMULATION

$$\rho_{m+1} = a_1 \rho_m + a_2 \rho_m^2 + a_3 \rho_m^3$$

SEEMS TO WORK VERY WELL

$\vec{a}_{NN}$ $\vec{a}_{NO}$ $\vec{a}_{ON}$ $\vec{a}_{OO}$

SOME DIFFERENCES

CSEC ↔ ECLOUD

LINEAR MODEL:

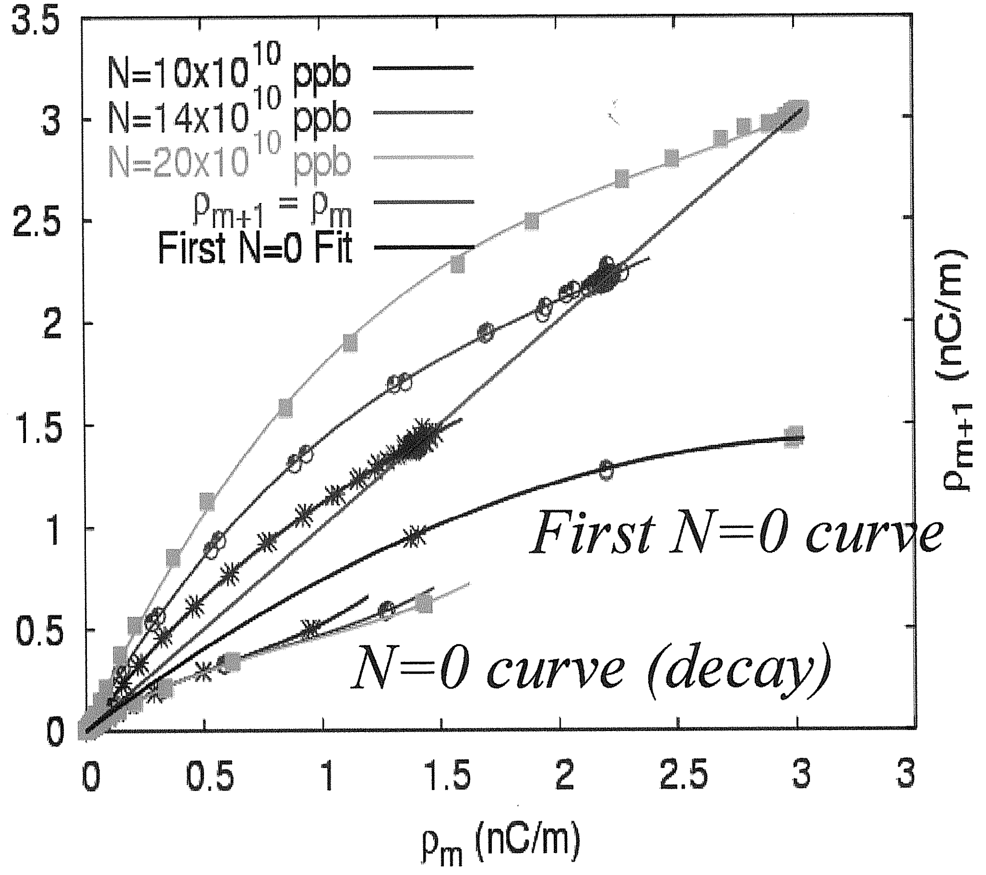
MOST SPARSE DISTRIBUTION IS BEST

DONE IN RHIC

2. Can the EC be represented by maps?

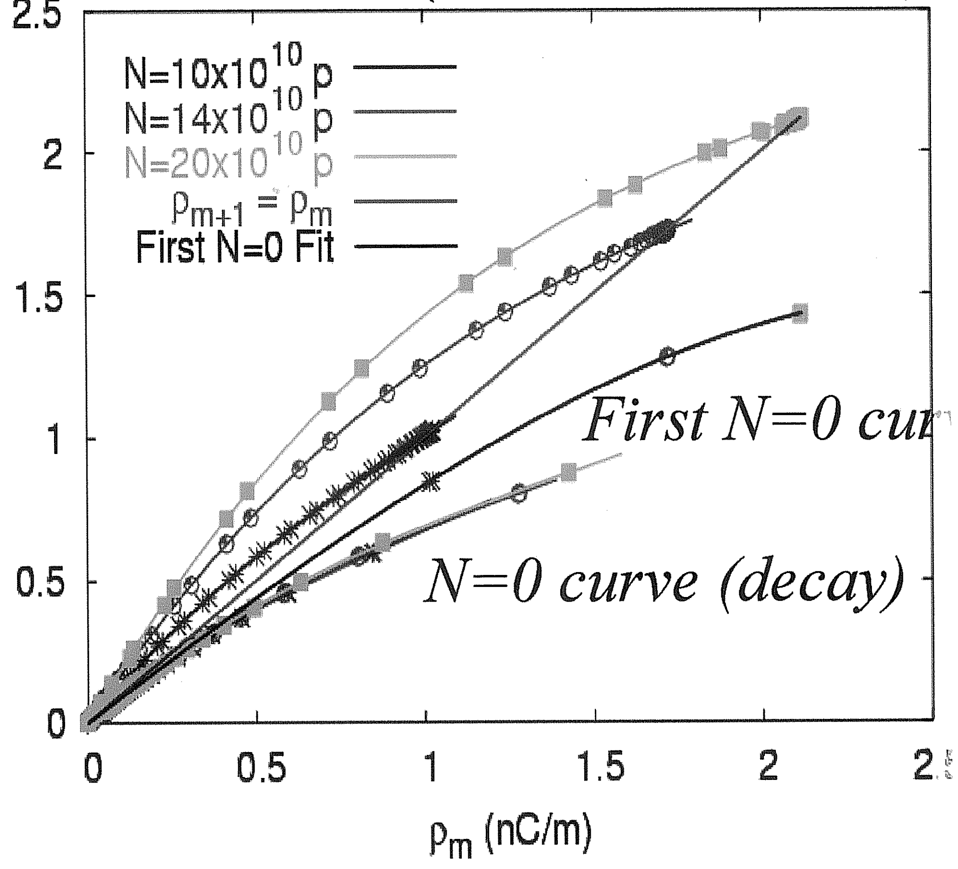
- Results for different N using CSEC (M. Blaskiewicz), and ECLOUD (F. Zimmermann). This is, results using different SEY parameterization:

CSEC



SEY from Furman & Pivi

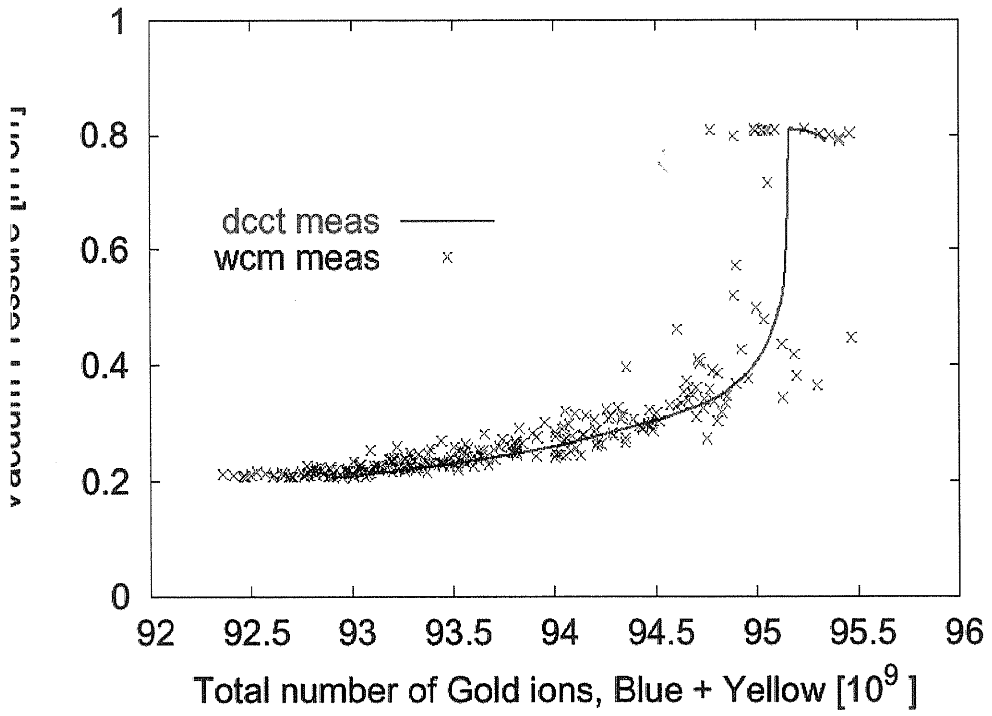
ECLOUD (Thanks G. Rumolo!)



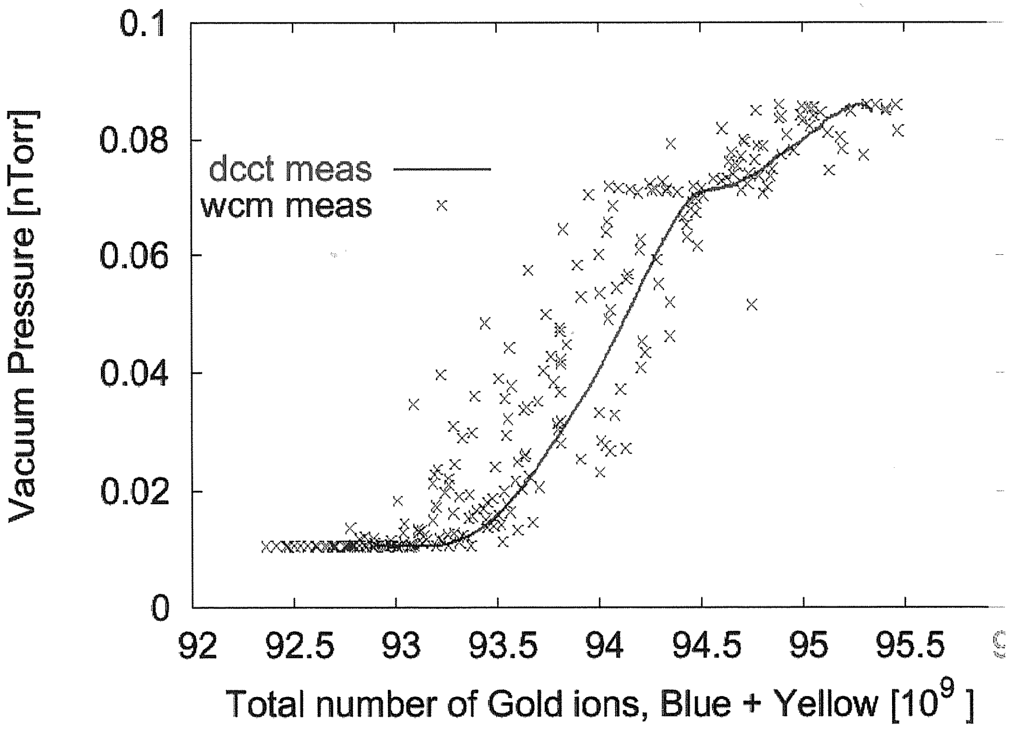
SEY from Cimino & Collins

4. EC phase transitions at RHIC

- (P, N) diagram for the previous case:



IR10: 1st order behavior



IR12: 2nd order behavior

HAS THIS BEEN SIMULATED

CODE DEVELOPMENT

A PROBLEM WHICH REQUIRES A SIMULATION

UNDERSTANDING OF THE RELEVANT PHYSICS

UNDERSTANDING OF RELEVANT NUMERICS AND COMPUTATIONAL PROCEDURES / PROBLEMS

IMPLEMENTATION OF CODE

BENCHMARKING WITH

- ANALYTIC MODELS
- OTHER CODES
- EXPERIMENTS

MAKING PREDICTIONS

RELEVANT PHYSICS

PARTICLE MOTION AND FIELDS ARE WELL UNDERSTOOD

SURFACE PHYSICS IS PROBLEMATIC

- DIFFICULT PROBLEM
- LIMITED KNOWLEDGE OF ACTUAL MATERIAL

CARRY OUT EXPERIMENTS WITH WELL KNOWN SURFACES

A COMMON LIBRARY OF SURFACE SIMULATION ROUTINES CAN BE HELPFUL (CMEE)

- EASY ACCESS FOR CODES
- BETTER BENCH MARKING
- SHOULD CONTAIN COMPEETING MODELS

WHICH PARAMETERS ARE RELEVANT?

NUMERICS AND COMPUTERS

CODES CAN BE TIME CONSUMING

THEY MAY NEED INTEGRATION INTO LARGER FRAMEWORK

IN PARTICULAR INSTABILITIES CAN BE NUMERICALLY CHALLANGING

-> CAREFULL CHOICE OF ALGORITHMS

-> PARALLEL COMPUTING

-> MODULAR DESIGN
  - LIBRARY
  - INTEGRATION INTO EXISTING CODE

IS THERE A SINGLE APPROACH ?

WHAT ABOUT SELF-CONSISTANCY?

BENCHMARKING

TALKS AND DISCUSSION SAW
BENCHMARKING AS VITAL

CODE ↔ FULL ANALYTIC MODEL

DURING DEVELOPMENT
→ CORRECTNESS OF MODULES

OF FULL CODE
→ INTERPLAY OF MODULES

CODE ↔ APPROXIMATE ANALYTIC MODEL

CAN INCREASE LEVERAGE
MORE DELICATE
CAN HELP TO VERIFY APPROXIMATI

CODE ↔ CODE

VERY IMPORTANT
ONLY WAY TO VERIFY CODES
IN THE INTERESTING REGIME

CODE ↔ EXPERIMENT

THE MOMENT OF TRUTH

INDISPENSIBLE

CAN BE NEXT TO IMPOSSIBLE

CAN ALSO BE MISLEADING

TALKS + DISCUSSION:

WE SHOULD FOSTER
BENCHMARKING OF CODES

HOW CAN WE IMPROVE BENCHMARKING?

DEFINE SET OF STANDART CASES

SOME CASES EXIST

MORE MAY BE NEEDED

- TO COVER ALL RELEVANT CASES
- TO ALLOW ALL CODES TO PARTICIPATE

→ MAYBE SHOULD HAVE SOME INDEPTH DISCUSSION

CODE COMPARISON FOR EPAC

MORE AND IMPROVED EXPERIMENTS

SUMMARY

VERY INTERESTING TALKS

PROGRESS IN

SOPHISTICATED SIMULATIONS
AND TOOLS

ANALYTIC APPROACH

SIMPLYFIED